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Volume 69 Number 4

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The DD-936, named for Stephen Decatur, on her delivery trials. She was constructed by Bethlehem's Quincy Yard.

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CORROSIVE MEDIA	METAL RESISTANCE	
	ZIRCONIUM	TITANIUM
Sulfuric Acid	excellent to good below 80%	good below 5%
Nitric Acid	excellent	excellent
Hydrochloric Acid	excellent	good below 10%
Phosphoric Acid	excellent to fair below 85%	poor
Chromic Acid	excellent	excellent to good
Aqua Regia	poor	excellent
Wet Chlorine Gas	poor	excellent
Chlorine Water	excellent	excellent
Sodium Hydroxide	good below 90%	good below 50%
Ferric Chloride	poor	excellent
Calcium Chloride	excellent	excellent
Cupric Chloride	poor	excellent
Sodium Chloride	excellent	excellent
Ammonium Chloride	excellent	excellent
Aluminum Chloride	excellent	excellent to fair

Corrosion resistances of zirconium and titanium to typical chemicals are shown above.

At right is a steam jet made of zirconium which has given trouble-free performance after a year in hydrochloric acid service. For comparison, a throat piece from a steam jet made of cast iron is shown after only a week of similar service.

ZIRCONIUM AND TITANIUM LICK TOUGHEST EQUIPMENT CORROSION PROBLEMS

The use of zirconium, titanium, or alloys of these metals now makes it possible to fabricate equipment that is corrosion-resistant to almost every substance encountered in industry. Even with such difficult-to-handle chemicals as chlorides and oxidizing acids, equipment can have extremely long service life. Problems of product contamination in chemical and food processing can be virtually eliminated.

Costs are cut in two ways. Direct maintenance costs are lowered, but even more important, costly downtime for the replacement of equipment can be avoided. These savings can more than compensate for the relatively high initial investment.

At the moment, equipment can be fabricated from titanium for about twice the price of stainless steel with even lower costs anticipated in the near future. When volume production is reached, commercial grade zirconium will probably cost only 50 to 75% more than stainless steel.

Wider application of these metals at reasonable cost is made possible by increased production and improved techniques provided by new U.S.I. facilities. By the end of this year, U.S.I.'s new titanium plant will add 5,000 tons to the nation's annual output. The new U.S.I. zirconium plant at Ashtabula, Ohio, employing a sodium-reduction process, will be able to supply 1,000,000 pounds of zirconium platelets to industry in 1958, in addition to meeting Atomic Energy Commission commitments.

If you have a corrosion problem, it will pay you to investigate the advantages of using these new metals. For more information, write to Bill Greenleaf, Manager of Metals Development.

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Of our national imports and exports, 78 per cent arrive and depart in vessels of foreign registry. We are a maritime nation with but a token fleet of cargo vessels flying our flag, outnumbered and largely over-age.

For our national welfare, we need American flag vessels in number. These ships must be fast, modern, and easily convertible for defense. It is time we become rightfully assured that the vital necessities of our way of living can reach us at all times. M-387

The Babcock & Wilcox Company, whose boilers supply power to the U.S.S. Saratoga, the U.S.S. Forrestal, and so many thousands of other American ships, is continuing to work in the tradition of engineering excellence which has made the U.S.A. the world's leader in the design and construction of merchant and naval vessels.

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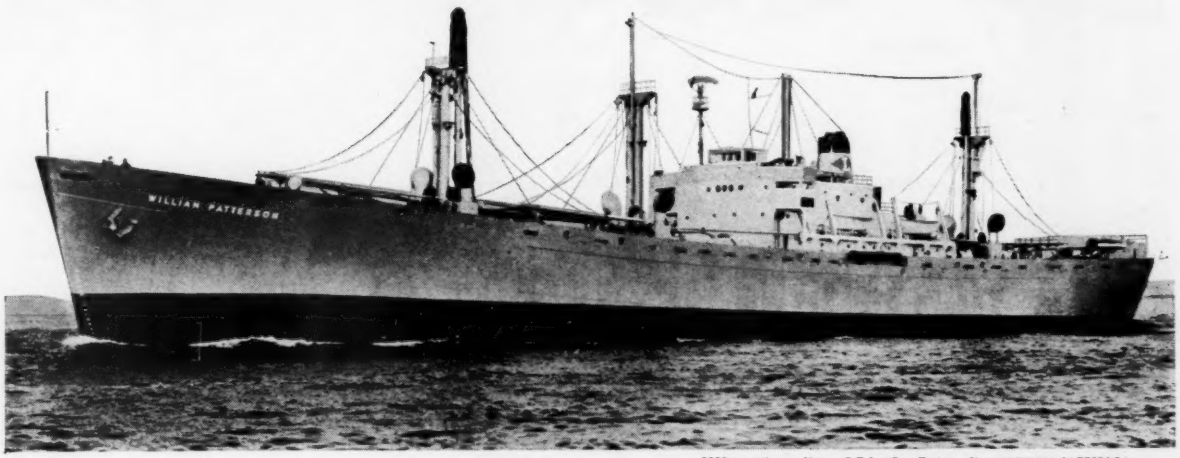

9000-ton Liberty Ship—G.T.S. (Gas Turbine Ship) WILLIAM PATTERSON

First in the United States—and largest of its type in the world—General Motors' new Free-Piston-Gas-Turbine Engine marine installation has successfully passed sea trials in the converted Liberty Ship WILLIAM PATTERSON, which will be operated in transatlantic service for the Government by Lykes Brothers Steamship Company.

This great new marine power plant was engineered and developed by Cleveland Diesel, aided by hundreds of scientists and engineers at General Motors' vast Technical Center in Detroit, other Divisions of General Motors and SEME-SIGMA, France.

It was installed in the WILLIAM PATTERSON by the Bethlehem Steel Company Shipbuilding Division, Baltimore Yard, under the direction of the Office of Ship Repair and Construction, Maritime Administration, U. S. Department of Commerce.

The success of this new Free-Piston-Gas-Turbine power plant marks a big forward step in the Maritime Administration's program to improve the performance standards of America's Liberty Ships.

It holds tremendous promise for the future as General Motors engineers work on continuing improvements as well as other applications for this new form of power.

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ENGINE DIVISION OF GENERAL MOTORS, Cleveland 11, Ohio

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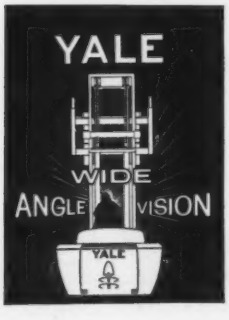

Only new Yale 15,000-20,000 lb. capacity Gas Trucks offer you "Wide-Angle Vision"—Yale's exclusive feature that gives the driver 300% more visibility for greater safety. Design advances such as nesting of upright channels; wide spacing of lifting channels and hoisting cylinders; high, center location of driver's seat assure not just unobstructed center visibility but also a greater arc of vision. New Yale Gas Trucks also feature a low center of gravity, a broader lifting base, wide channel-roller spacing and large high-flotation tires for maximum stability even under capacity-load conditions. Lifting speed of 60 feet per minute, fast controlled lowering, travel speed up to 20 MPH assure fast cycle operations.

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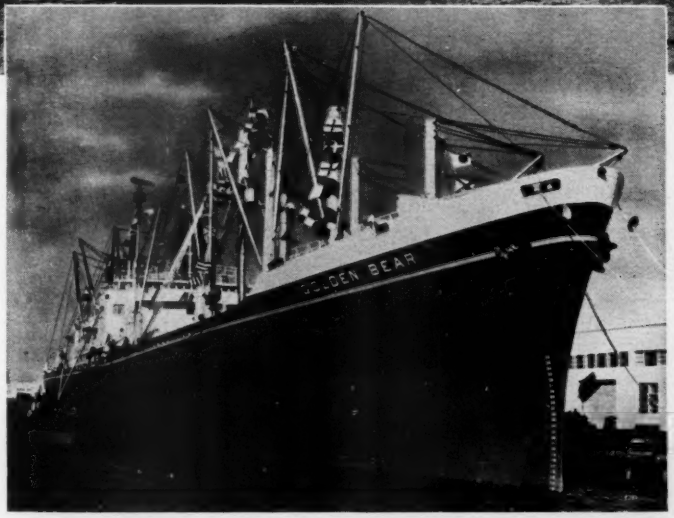

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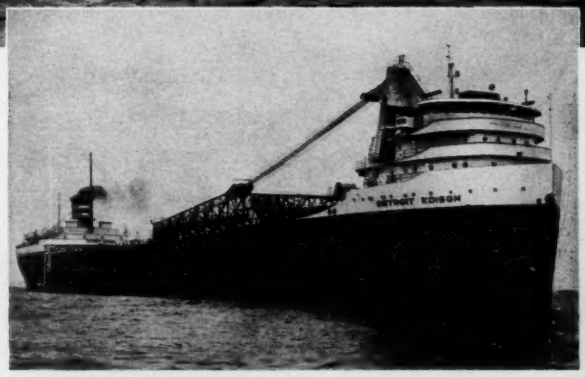

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Commodore Isaac Hull was captain of the U. S. S. CONSTITUTION during her famous engagement with H. M. S. GUERRIERE in which his ship gained the name "Old Ironsides."

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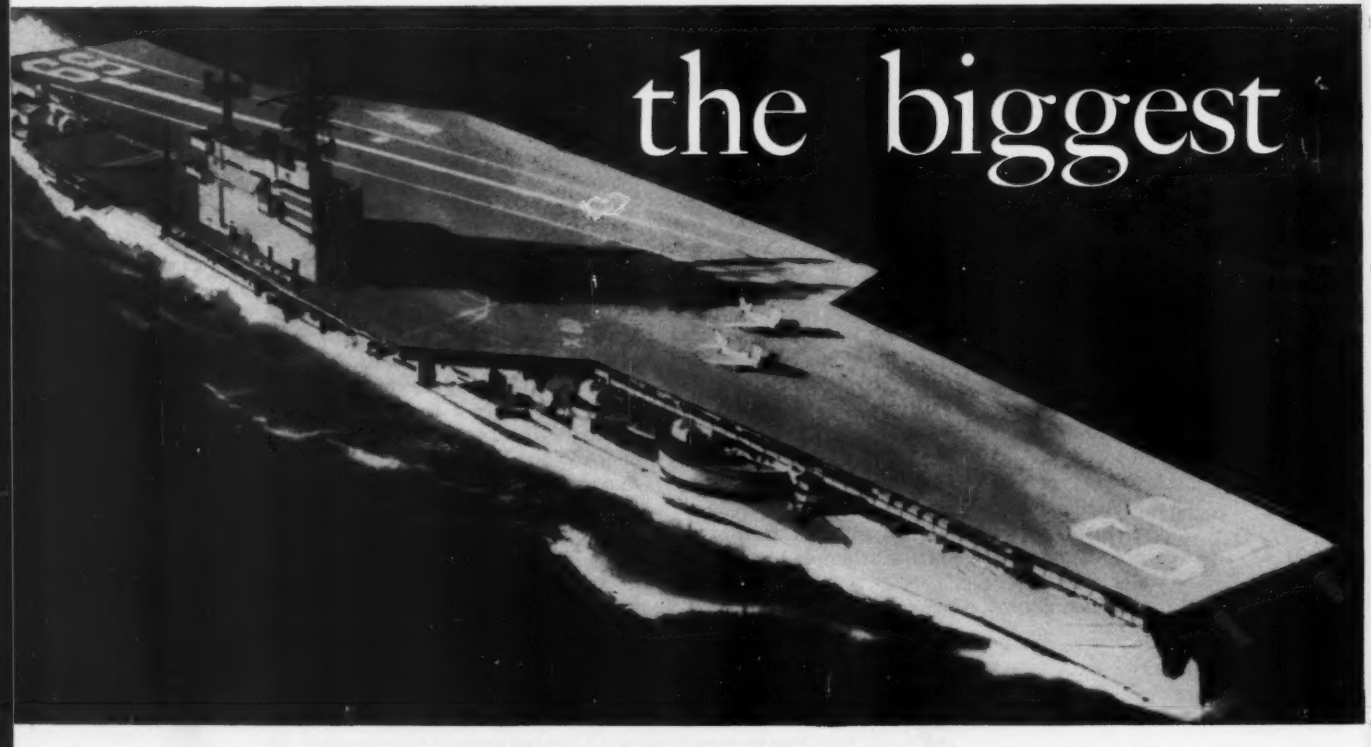

USS FORRESTAL

An aircraft carrier so big the liners Queen Mary and Queen Elizabeth could fit on her deck. Yet Westinghouse engines make the Forrestal one of the fastest ships afloat.

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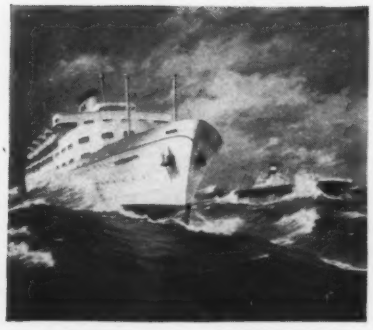

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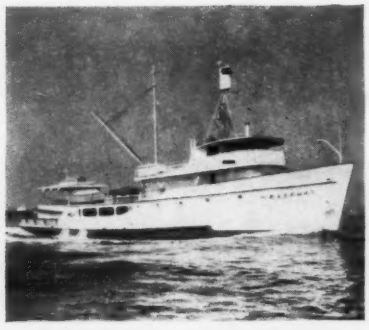
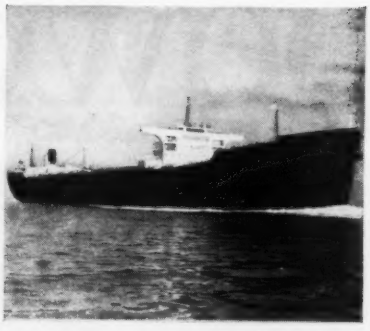


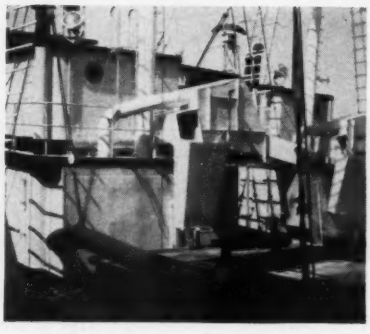
New Tuna Clipper — The "Westport" ranges far and wide for her 340-ton load of tuna. A Monel shaft that resists breakage, drives her home safely.



Ore Carrier — The S.S. Ore Chief uses Monel alloy for strength and corrosion resistance in cargo hoists, winches and valve stems. Real economy!

ALL THESE VESSELS

Fast Work Boat—The "Marlin" speeds work crews to offshore drilling platforms. Her Monel shaft makes possible all-weather, round-the-clock runs.



Menhaden Fleet — To separate fish from sea water drawn aboard from nets through flexible hose in foreground, Menhaden uses Monel fish separators.

Experimental Boat— The "Solar Meteor's" gas-turbine engine revs up to 20,000 rpm in seconds. A Monel shaft takes the full-power whip in stride.

WORK BETTER LONGER!

Harbor Tug—The "Angels Gate" guides heavy derrick barges for the Los Angeles Harbor Department. Her 9-inch Monel shaft reduces upkeep.

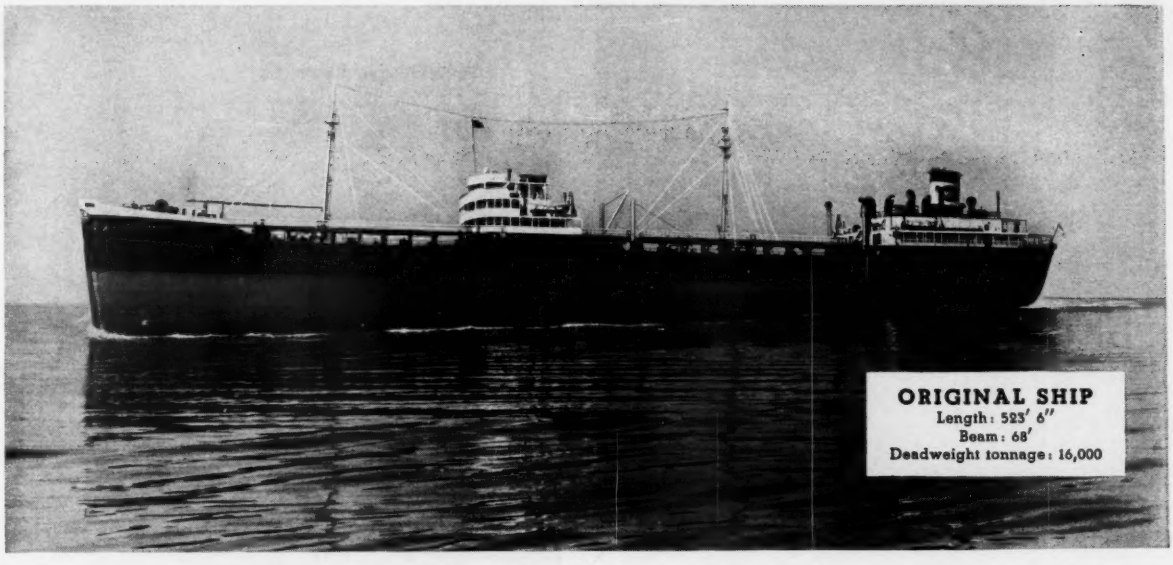
Mighty Midget— The 34-inch tug "Polaris" can tow a loaded canoe with her 4-5/16 inch long "R"* Monel free-machining nickel-copper alloy shaft.

For Equipment that must withstand corrosion, choose Monel alloy.

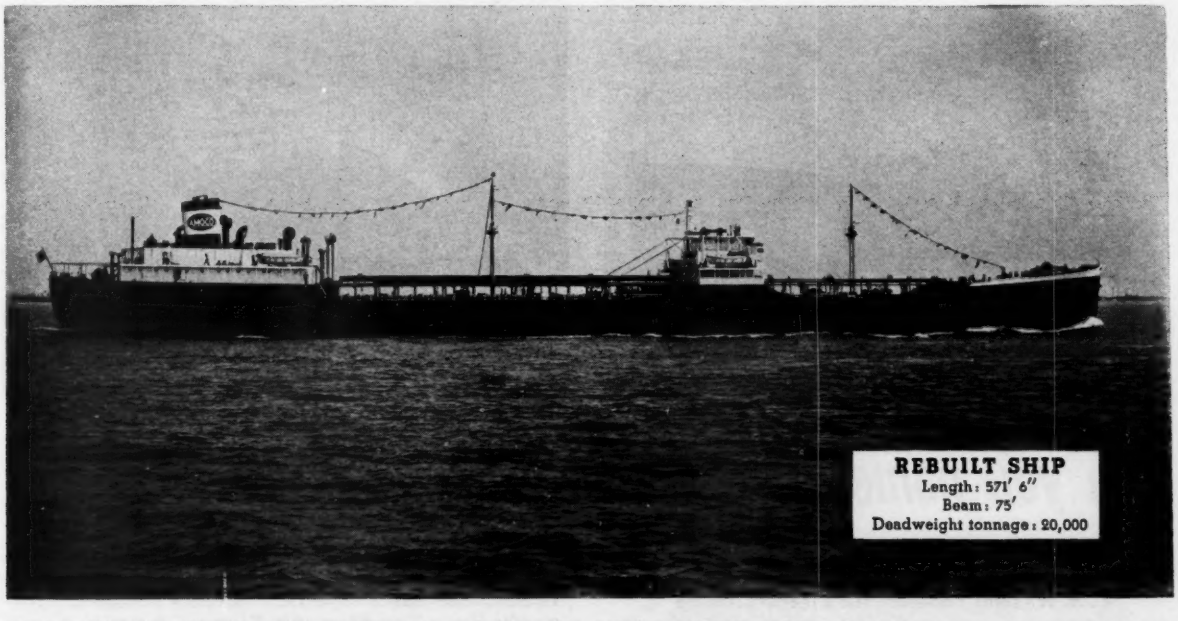
*Registered trademark

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street New York 5, N. Y.

MONEL
THE SEAGOIN'* METAL



NEWPORT NEWS "JUMBOIZES" WARTIME T-2 TANKER



READ WHAT NEWPORT NEWS IS DOING TO HELP OVERCOME TANKER OBSOLESCENCE

The Amoco Delaware is one of four T-2 tankers to undergo a unique "jumboizing" operation at the Newport News Yard. That required only 42 working days.

Along with other alterations, her cargo tanks were completely replaced with a longer section of wider beam. Three more of these 310-foot sections are building at Newport News to complete conversion of additional tankers.

Enlargement of the DELAWARE, according to Vern Drew, Amoco's General Manager of Marine Operations, resulted in no appreciable loss of speed with the increase in capacity from 16,700 to 20,000 deadweight tons.

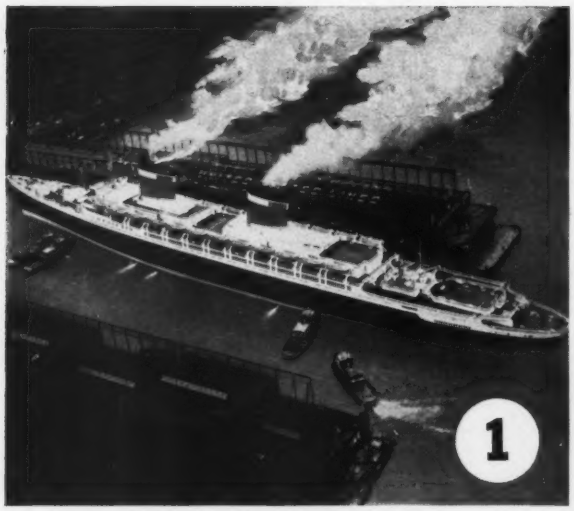
"Giving these ships a new life of 15 years," says Mr. Drew, "is one way of beating the block obsolescence of America's tanker fleet."

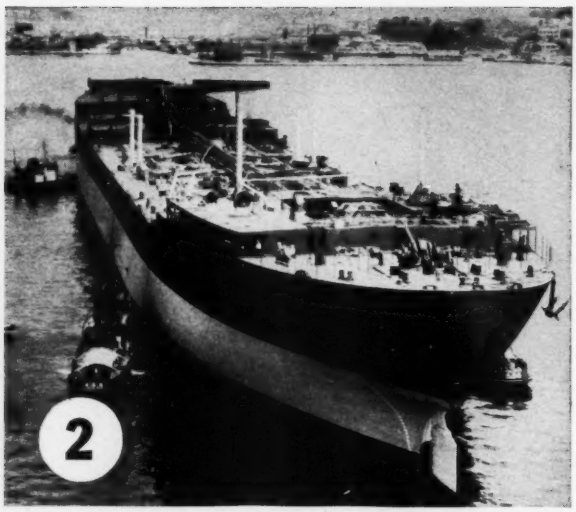
Operation Jumbo is another example of the "tough" ones at Newport News. And for good reason. Newport News has the fully integrated facilities and the skilled personnel to turn out extensive conversions and alterations in the shortest possible time.

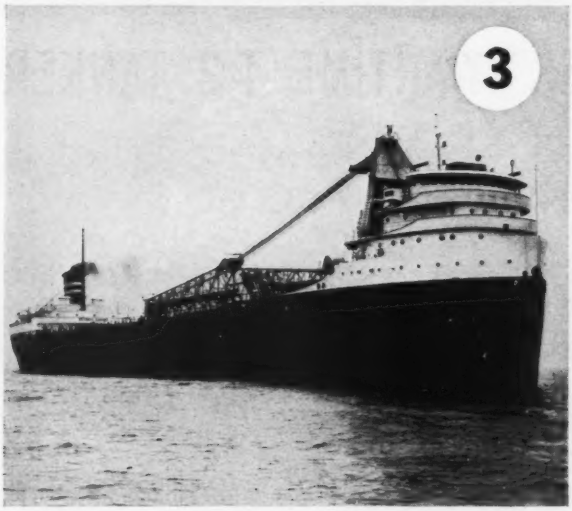
Your inquiries about T-2 conversions are invited.

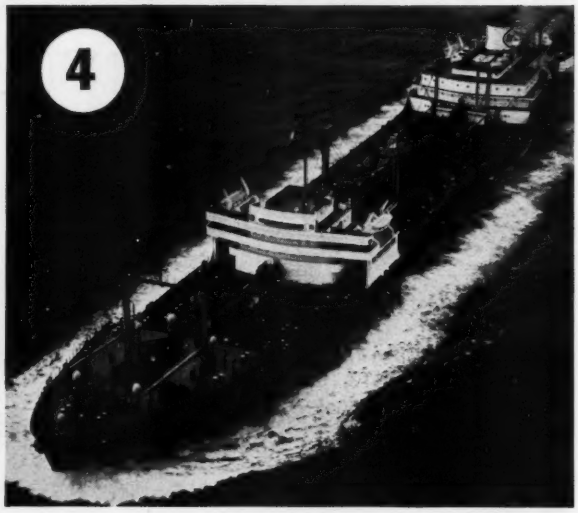
Engineers . . . Desirable positions available at Newport News for Designers and Engineers in many categories. Address inquiries to Employment Manager.

Newport News
Shipbuilding and Dry Dock Company
Newport News, Virginia









Can you name all 4 Wheeler-equipped ships?

See if you can identify these ships, all of which have C. H. Wheeler Tubejet® Air Ejectors aboard

NUMBER 1 is the world's fastest and most modern passenger liner, the S. S. United States. She has 4 Main Air Ejectors, 6 Main Feed Pump Condenser Air Ejectors, 6 Turbo-Generator Condenser Air Ejectors and 2 Contaminated Exhaust Condenser Air Ejectors made by C.H. Wheeler.

NUMBER 2 is the world's first supertanker, the 80,000-ton Universe Leader. She has several C.H. Wheeler Main and Auxiliary Air Ejectors.

NUMBER 3 is one of the most modern bulk-cargo vessels in operation on the Great Lakes, the Detroit Edison. She has 2 of C.H. Wheeler's compact, lightweight Twin Two-Stage Air Ejectors aboard.

NUMBER 4 is the most powerful single-screw ship ever built, the Esso Gettysburg. Included in her equipment are dependable, efficient C.H. Wheeler Main and Auxiliary Air Ejectors.

Whether you're an expert or not at identifying ships, you can easily be one at identifying ship equipment, because nearly every new large vessel afloat is equipped with C.H. Wheeler Tubejet Air Ejectors!

Marine Division

C. H. Wheeler Mfg. Co.

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The Glacier breaking ice in McMurdo Sound. Mt. Erebus in background. (Official U.S. Navy Photo)

SMASHING THE ANTARCTIC ICE BARRIER
with an 8,600-ton blow!

To the Glacier, our Navy's largest and most powerful icebreaker, driving a path through ice up to 22 feet thick is all in the day's work. Here it is shown breaking a channel through 17 feet of solid ice at approximately 18 knots in Antarctica's McMurdo Sound as part of Operation Deep Freeze I and II. In view of the importance of communications at the bottom of the world, the Glacier is virtually a floating electronic laboratory. It contains nine AN/SRR-13A and seven AN/SRR-11 radio receivers, as well as two AN/SPA-YA Range Azimuth Indicators, one on the bridge and the other in the CIC. All of this RCA equipment has given continuous and dependable service, unaffected by the tremendous shocks to ship and gear, as 21,000-horsepower engines send the ship crashing forward under conditions never before faced by any icebreaker.

USS Glacier driving through pack ice in Ross Sea. (Official U.S. Navy Photo)

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RADIO CORPORATION of AMERICA

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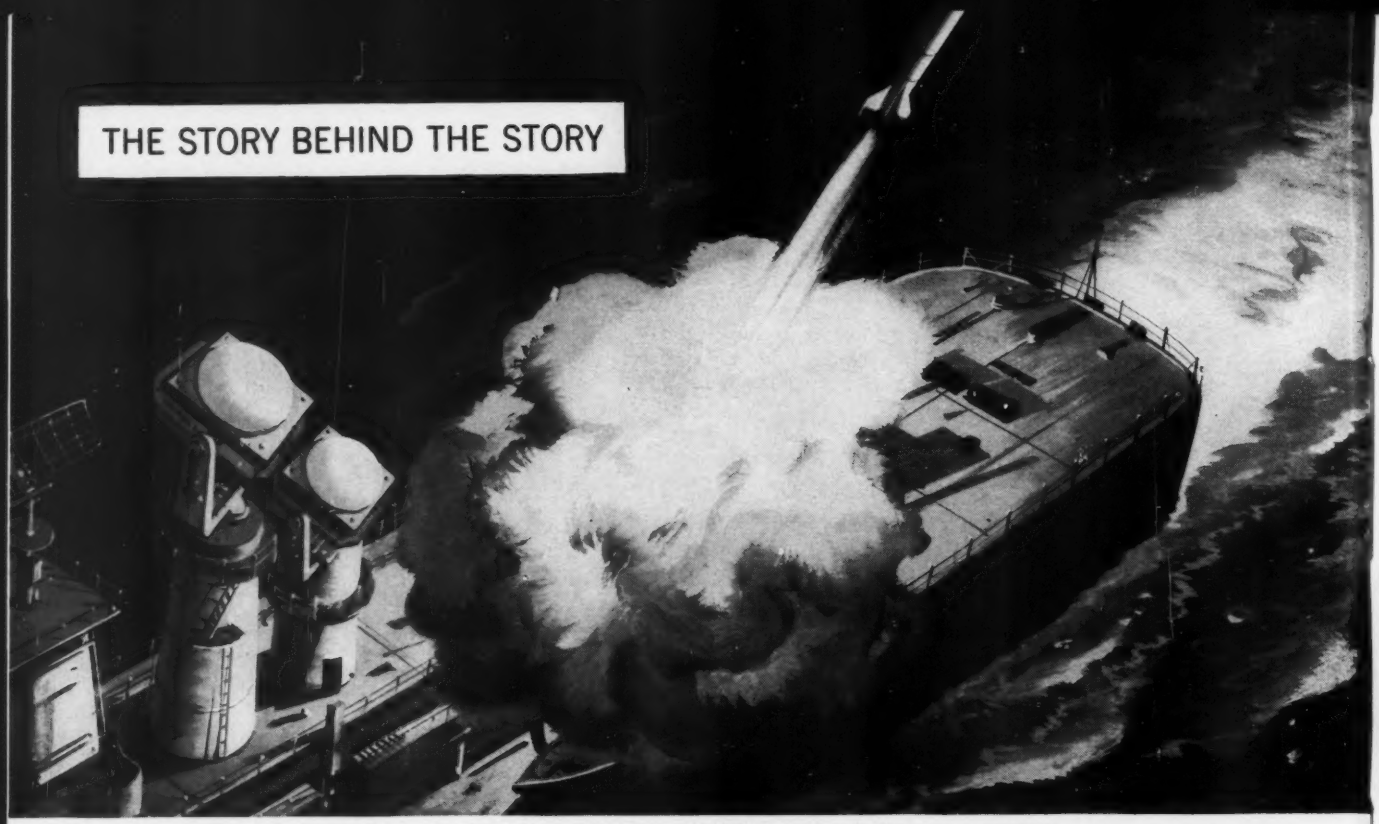
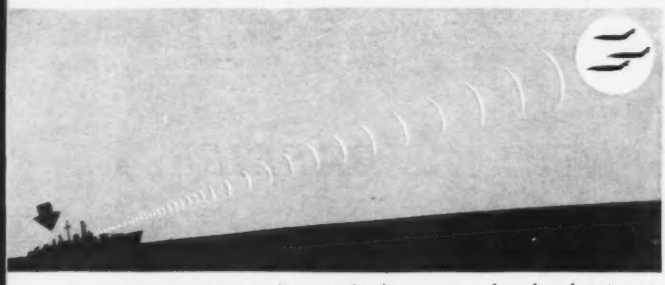
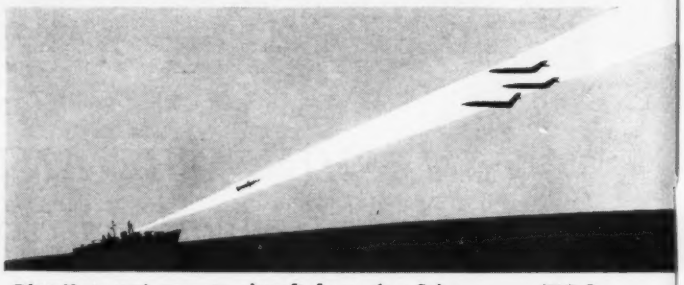
THE STORY BEHIND THE STORY



Terrier missile roars into sky from *U.S.S. Canberra*, first Navy missile ship equipped with Sperry SPQ-5 long-range radar. Antennas resembling searchlights track approaching aircraft and simultaneously launch and guide missiles with extreme accuracy.



Tracking aircraft miles past horizon, new radar pinpoints targets approaching from any direction at all heights.



Singling out separate aircraft from close-flying group, SPQ-5 radar guides missiles along radar beam to selected targets.

SUPER-ACCURATE RADAR EXTENDS NAVY DEFENSE

Tracks far-distant aircraft, enables deadly missile interception

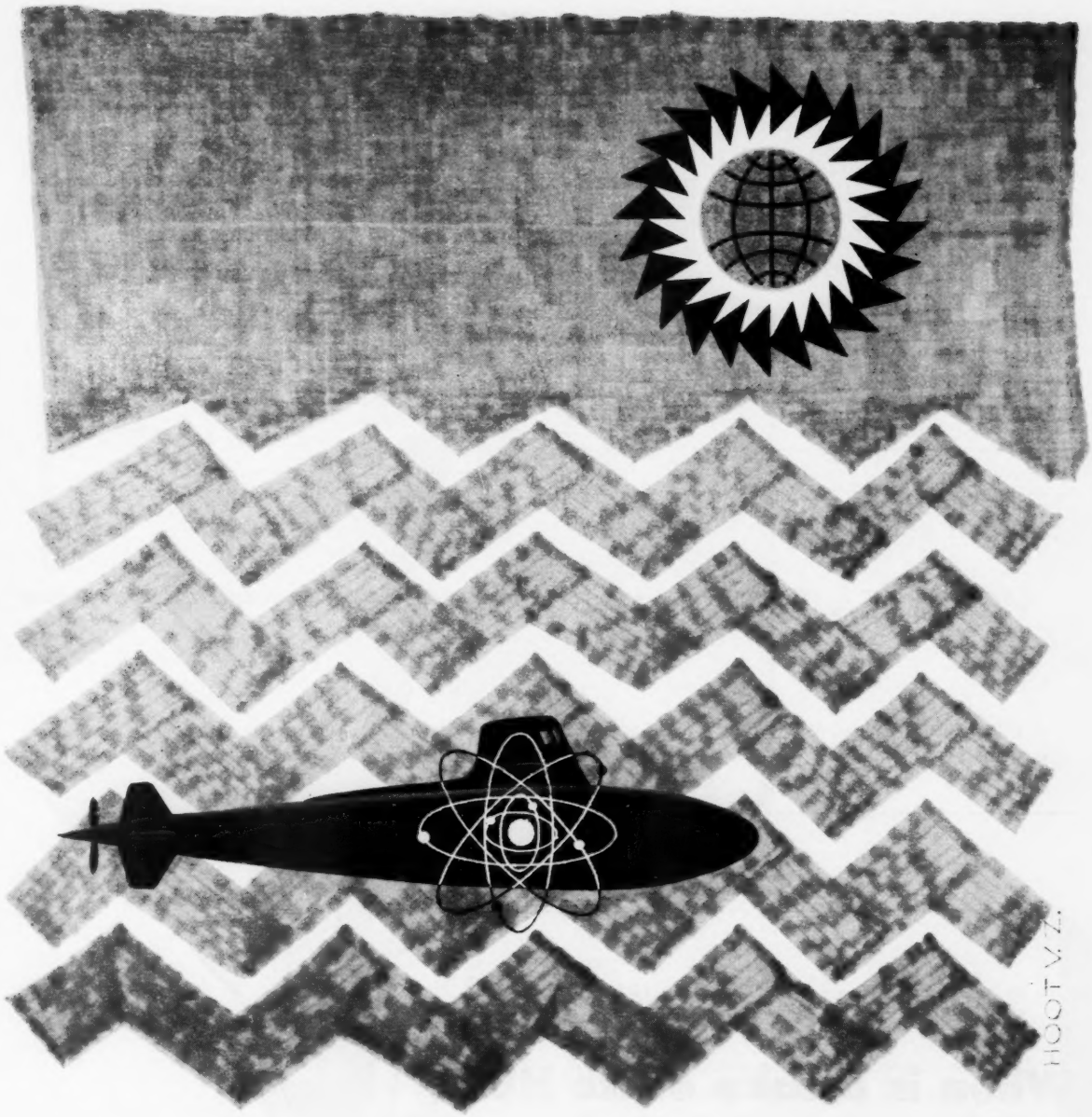
Below decks trained operators monitor on radarscopes the automatic tracking and destruction of targets.

Until recently, the head-on silhouette of an aircraft approaching at supersonic speed has registered as little more than a microscopic dot on radarscopes—until the plane itself was dangerously close. Sperry's development of the SPQ-5 radar for the Navy's Bureau of Ordnance now makes engagement of a potential enemy possible while he is still far beyond the horizon.

Resembling searchlights, the antennas of these super-radars cover the complete expanse of the skies, in all directions and at all altitudes. On radarscopes below decks, distant aircraft can be studied, and the course of individual planes can be plotted. In event of hostilities, full salvos of missiles like the Terrier can be launched and guided straight to their targets, riding the same powerful radar beam.

Development of this long-range super-radar boosts the accuracy and range of the antiaircraft armament aboard the Navy's new missile ships. It also serves notice to prospective trespassers that the odds against success in a surprise attack have grown still longer.

SPERRY GYROSCOPE COMPANY
Great Neck, New York
DIVISION OF SPERRY RAND CORPORATION



GLOBAL A-SUB GETS SPECIAL STEEL SKIN

■ Look at the revolutionary shape and clean lines of the Navy's newest atom sub *Skipjack* — designed from the keel up for continuous underwater operation!

She'll be the world's fastest attack sub. Her nuclear power plant will give her globe-ranging endurance — submerged. And a special type of Lukens alloy steel plate will provide her streamlined hull with the strength to withstand deep-sea pressures and explosive shock.

This project, like others of such high importance, demanded many special steels, plus the kind of specialized knowledge that Lukens puts at all industry's disposal. Fabricators in virtually every field have long called upon Lukens for teamwork. In fact, even back in 1869 when Jules Verne's fictional submarine first fired the world's imagination, Lukens had been a leading plate producer for 44 years.

LUKENS STEEL COMPANY, COATESVILLE, PA.

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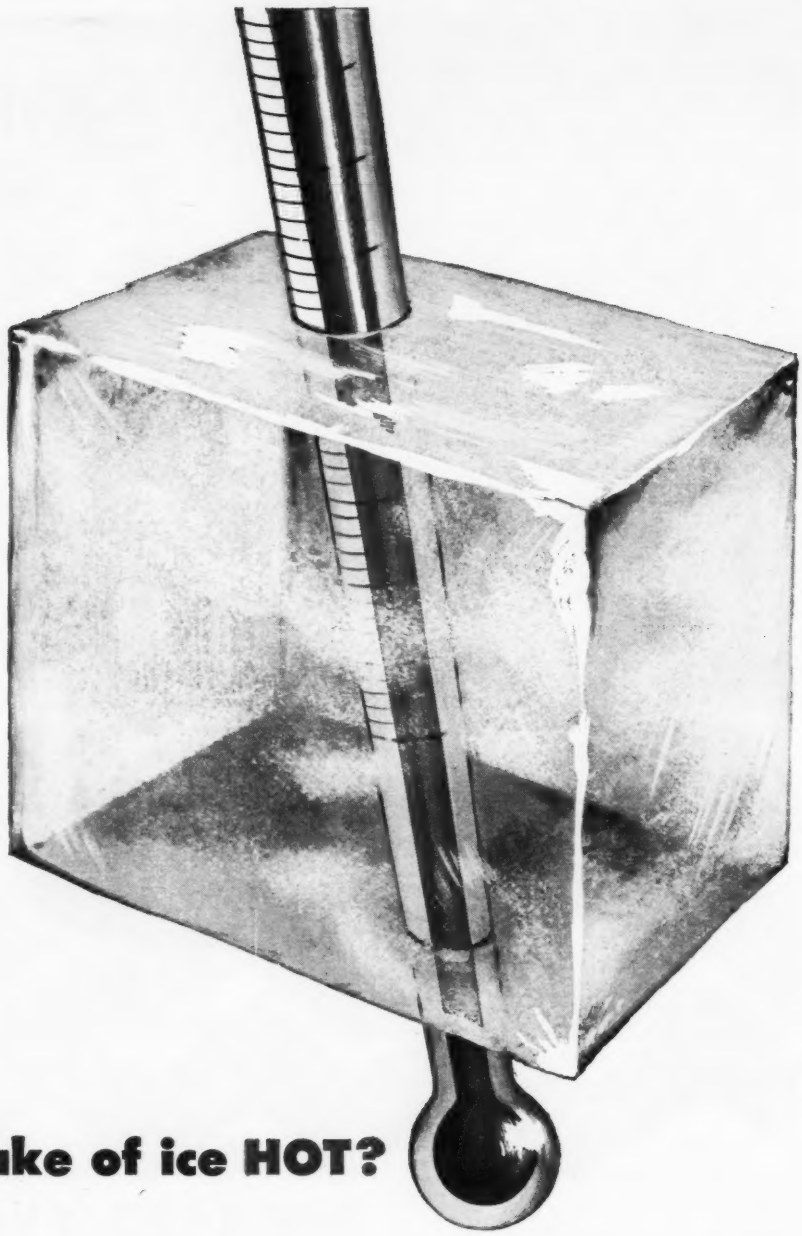

When is a cake of ice HOT?

To the latest infrared sensing devices, *even ice is hot!*

Transparent to a wider range of infrared frequencies than any other IR housing or lens, new Raytheon silicon optics allow even the faint radiations from subzero objects to reach detectors. Formerly, objects had to be 500° F. or hotter for detection at equal ranges. The new silicon optics improve detector performance, permit them to locate targets at greater distances in total darkness!

This latest development typifies creative engineering at Raytheon—constant exploration and experimentation to achieve components and products of utmost efficiency and reliability.

RAYTHEON

Excellence in Electronics

RAYTHEON MANUFACTURING COMPANY, WALTHAM 54, MASS.

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I hereby apply for membership in the U. S. Naval Institute and enclose $3.00* in payment of dues for the first year, the PROCEEDINGS to begin with the_____issue.

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ECONOMY**

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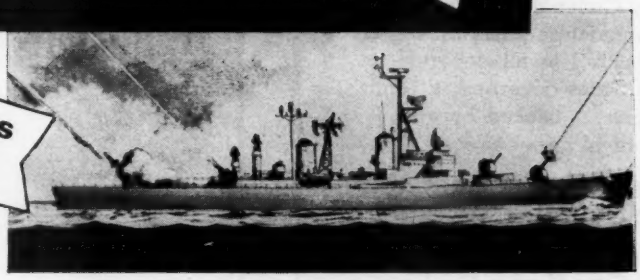
FW Powered for dependability and economy

FIFTH FORRESTAL CLASS CARRIER

DESTROYERS DD 947 and 948



NEW DLG CLASS FRIGATE

First of its class now under construction

NAVAL POWER is steam power. And this service, more than any other, demands the last word in steam-plant *dependability*. To increase cruising range, boiler *efficiency* is also important.

On *both* counts, Foster Wheeler D Type steam generators have achieved an enviable performance record. That's why they are used on so many different types of vessels—from destroyers to aircraft carriers—tugs to tankers—ferries to passenger ships.

Foster Wheeler means proved *reliability* and *efficiency*—not only in steam generators, but in condensers, economizers and other marine auxiliaries as well. *Foster Wheeler Corporation, 165 Broadway, New York 6, N. Y.*

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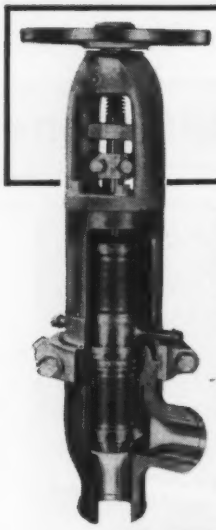

"OIL TO ATOMS"
brings this new look in valves

This is the type of valve found in the engine rooms of the *Nautilus* and the *Seawolf*, and in Navy's plans for added atomic-powered construction. The valve design and application are new, but the brand is well known for dependability.

From the start of nuclear power development, Crane was ready for the problems of controlling radioactive fluids. Crane had the skill in valve metallurgy and engineering. Crane had the background in quality production.

Today . . . tomorrow . . . as atomic power grows, you can count on Crane to meet Navy's needs. Your inquiry is invited.

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NEW YORK

CONDENSER TUBE CLINIC

ARTHUR W. TRACY, Metallurgical Engineer, The American Brass Co., Waterbury, Conn.

Some operating factors that affect tube life

COMPOSITION OF THE COOLING WATER

The quantities of cooling water used in condensers preclude any treatment to make the water less corrosive, except where the water is recirculated.

In general, however, plants located inland will have relatively noncorrosive cooling water. Plants situated on tidewater will have corrosion problems, especially if the water is polluted with industrial or domestic sewage and conditions are such that organic matter in the sewage can ferment under anaerobic conditions, with the consequent formation of sulfides. Water in an enclosed harbor or dead-end channel, where the water is more or less stagnant, is particularly subject to infestation by anaerobic bacteria.

PREVENTIVE MAINTENANCE

Frequent cleaning of tubes to remove slimes containing bacteria and the simultaneous removal of sulfide scales will increase tube life. Chlorination of polluted water at frequent intervals, or periodically filling the water spaces in the condenser with chlorine gas, will not only remove the slimes but may also aid in breaking down the unwanted sulfide films which have formed on the inner walls of the tubes.

MEDIA BEING COOLED OR CONDENSED

It is not usually possible to change the corrosive properties of products being handled in the process industries. The venting of noncondensable gases, however, will markedly increase tube life. This is particularly true on the steam side of boiler feed-water heaters and other steam-heated equipment where accumulations of oxygen, carbon dioxide, and ammonia can cause rapid failure of condenser tubes.

TEMPERATURE

The corrosion rate of metals usually increases with increasing temperature. At low water velocities, the formation of gas bubbles on the water side of a tube can initiate pitting which may continue even after the bubble has disappeared. In such cases, a judicious increase in water velocity will insure longer tube life, provided the velocity is not increased to a point where impingement corrosion can occur.

TECHNICAL HELP IN SELECTING TUBES

Your situation may require special consideration and analysis. We are always ready to help and advise in the selection of the right alloy to give best service. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 5780B

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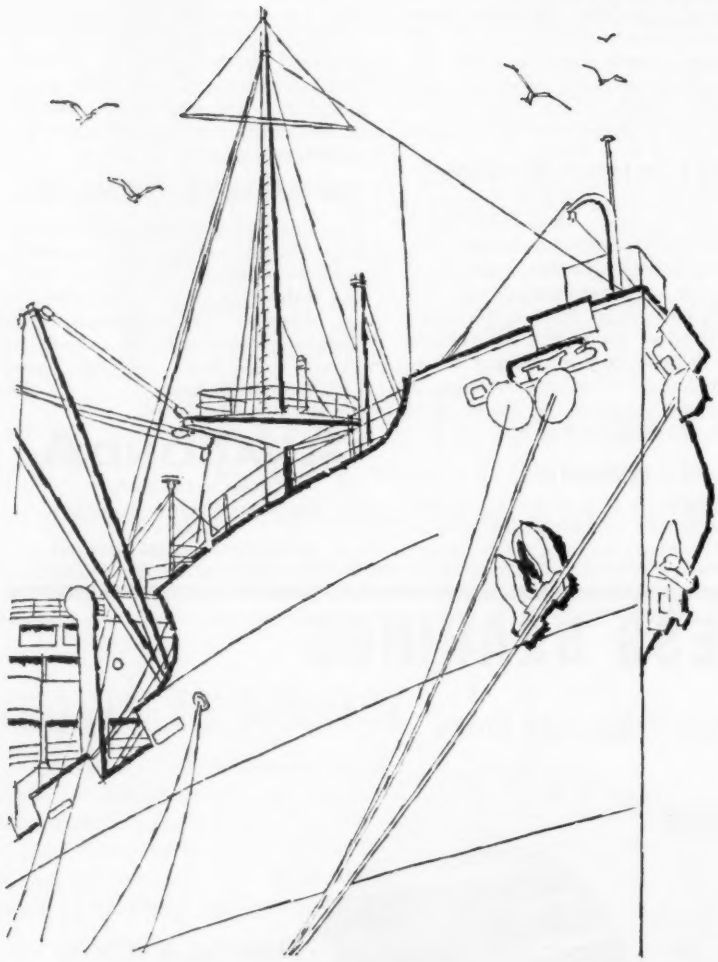
Akron, Ohio

For shipbuilding . . .

USS "T-1" constructional alloy steel

brings you STRENGTH!



USS "T-1" Steel—new, quenched and tempered alloy plate steel—has a very high yield strength of 90,000 psi, which makes possible stronger decks, plating, masts, booms, posts and built-up structurals. When you use USS "T-1" Steel to replace other steels, its tremendous strength permits you to reduce weight by using thinner gages . . . or to increase strength substantially if you use USS "T-1" Steel in the same gages.

TOUGHNESS!

Exceptional resistance to impact characterizes USS "T-1" Steel. It has demonstrated its ability to take high impact loading without failure at temperatures as low as 38° below zero. Consider USS "T-1" Steel for cargo holds, bow and bulwark plating . . . for any equipment that is subject to impact even at extremely low temperatures.

WELDABILITY!

For all its great strength and toughness —qualities usually found only in more expensive steels that are far more difficult to fabricate—USS "T-1" Steel is weldable! With proper electrodes, welds develop full 100% joint efficiency without pre-heating or post-heating. Thus USS "T-1" Steel lends itself to yard construction.

Where to use USS "T-1" Steel in ships . . . and why

Deck or shell plating	Strength and toughness make possible reduction in thickness and weight . . . or increase in strength. Weldability keeps fabrication simple.
Bulwarks	USS "T-1" Steel makes them strong, lightweight and resistant to corrosion.
Collision and other transverse bulkheads	USS "T-1" Steel increases strength with no increase in weight . . . sometimes makes weight reduction possible.
Machinery bases	USS "T-1" Steel increases strength and/or reduces weight.
Tubular masts, kingposts, booms	USS "T-1" Steel gives them high strength, light weight.
Funnels	Very high strength of USS "T-1" Steel permits weight reductions.
Cargo holds	USS "T-1" Steel provides toughness to withstand heavy impacts, plus abrasion resistance. Both help to reduce weight.

"USS" and "T-1" are registered trademarks.

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VOLUME 69 NOVEMBER 1957 NUMBER 4

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SECRETARY'S NOTES

Annual Meeting

The regular annual meeting for 1957 of the Society was held in the Navy Department on Thursday, 10 October 1957. This was the first of these meetings to be held on any date except the first Tuesday of October. One of the recent changes in the By-laws "unfixed" the date and permits the Council to select any date during the first half of October. About 50 members attended the meeting where principal business was to approve the nominations for offices of the Society to be voted on at the next election.

Election of Officers—1958-9

At the Annual Meeting, the members accepted and approved the recommendations of the nominating committee, without change. This committee which was composed of Rear Admiral Robert E. Cronin, U.S. Navy as Chairman with Captain Peter Horn, U.S. Navy, Captain J. A. Hartman, U.S.N.R., Mr. J. C. Niedermair and Mr. J. S. Melton as members had proposed the following slate of candidates. As a result of the members' approval, those names are now on the ballot which is before all voting members for voting and return by Christmas 1957:

For President to serve during 1958:
Rear Admiral Leroy V. Honsinger, U.S. Navy,
Deputy Chief of the Bureau of Ships

For Secretary-Treasurer to serve during 1958
Captain J. E. Hamilton, USN (Ret.),
present Secretary-Treasurer

Commander Joseph W. Naab, U.S. Coast Guard
Chief, Production Dept., U.S. Coast Guard Yard, Curtis Bay, Md.

For Members of the Council to serve during 1958 and 1959

Regular Naval Officers (two vacancies)

Captain Jamie Adair, U.S. Navy
Shipbuilding Asst. to the Asst. Chief of Bureau of Ships, Shipbuilding and Maintenance

Captain William Alden Brockett, U.S. Navy
Machinery Division Director, Shipbuilding and Fleet Maintenance Division, Bureau of Ships

Captain James Andrew Brown, U.S. Navy
Director of Hull Design Branch, Bureau of Ships

Captain Ivan Monk, U.S. Navy
Officer in Charge, Aircraft Carriers and Sea Plane Tenders, Bureau of Ships

Captain Philip E. Shetenhelm, U.S. Navy
Director of Machinery Design Branch, Bureau of Ships

Rear Admiral Philip W. Snyder, U.S. Navy
Assistant Chief of Bureau of Ships, Shipbuilding and Fleet Maintenance

Coast Guard Officer (one vacancy)

Captain C. S. Gerde, U.S. Coast Guard
Asst. Chief, Naval Engineering Division, U.S.C.G. Headquarters

Captain Richard D. Schmidtman, U.S. Coast Guard
Chief, Naval Engineering Division, USCG Headquarters

Naval Reserve Officer (one vacancy)

Captain Kenneth A. Ayers, USNR
Manager Eastern Division, Western Gear Corporation, 830 Washington Bldg., Washington, D. C.

Lieutenant Commander Donald E. Redmon, USNR
Asst. for Mechanical Engineering, Office of Director of Value Engineering, Bureau of Ships

Captain Louis H. Roddis, USNR
Deputy Director, Division of Reactor Development, Atomic Energy Commission, Washington, D. C.

Civilian (one vacancy)

Mr. Hugh E. Carlton
Manager, Washington Office, Foster Wheeler Corp., Suite 410, Tower Building, Washington, D. C.

Mr. Francis H. Engel
Asst. to Vice President Defense Electronics Products, R.C.A., 1625 K. Street, N.W., Washington, D. C.

Mr. Frederick J. Lindauer
Manager, Washington Office, Fairbanks, Morse and Co., 1012—14th Street, N.W., Washington, D. C.

Society Awards

As has been reported during the past the Society's only awards at the present time are made each year to the most promising Naval Engineer in the graduating class of each of The U.S. Naval Academy, The U.S. Coast Guard Academy and The U.S. Merchant Marine Academy.

It has been proposed that a major award of some kind be established for the purpose of Society recognition of some outstanding person to be selected by a set of definitive criteria. The Committee which was appointed to consider this matter wants to know something about the general feelings and opinions of the members in regard to a Society award. The Committee prepared a questionnaire which was mailed with the ballot for the annual election. It is hoped that members will give this serious thought and that returns on this questionnaire will give the Committee a good cross-sectional concensus to assist them.

Membership List

A new membership list will be published in (or mailed with) the February 1958 issue of the JOURNAL. This will be the first of these for two (2) years. In order to reduce the cost of preparing the list, the Council has decided that the name, rank, title, position and address of each member, as it appears in the current records of the Society will be used.

We know from the heavy returns of JOURNALS and correspondence that many members do not let us know when their addresses change. Many more do not say anything to us when they are promoted or change their positions.

We have enclosed with the ballot a card for the convenience of voting members to send in current information about themselves. Unfortunately this will not reach Associate and Junior members. All those who receive the cards are urged to fill them in and return them with the ballot or separately. All Associate and Junior Members are also urged to let us know at once, if they have any doubt as to the currency of our records, their present military rank or civilian title and company affiliation and correct mailing address.

The published list will contain the latest information which we can get into it. It will not be possible to assure that any information which reaches the Society office after 25 January 1958 can be incorporated in the list.

Company Membership

There continues to be an impression among some members that the Society offers company membership. This undoubtedly arises from the fact that some companies pay dues of their employees who are members, as a condition of their employment. It is in spite of the fact that each one, before joining, was required to fill out and sign a personal application and to obtain sponsors. When these members retire or change employment they fail to remember the obligations of their memberships and they are carried as delinquents and finally dropped; or their employer tells us to substitute someone else for the membership. This entails loss and extra expense to the Society, all of which we are sure can be avoided if each member will realize that his membership is a personal thing and carries with it the responsibilities of such membership.

By-laws

A copy of the revised By-laws is being included with the mailing of this issue of the JOURNAL to all members. As you are all aware a ballot containing 13 proposed amendments was sent out some time ago with return scheduled for 15 September 1957.

1339 ballots were returned. A very heavy majority favored adoption of all amendments. The most unpopular amendment, as was to have been expected, was the change in annual dues from $7.50 to $10.00. Slightly more than 10 percent of those who voted opposed the increase but since a two-thirds vote is sufficient for adoption, the increase was accepted. The opposition to each of the other changes was less than four percent.

As announced earlier in these notes the Council declared the change, to permit shifting the date of the annual meeting to be in effect at the last Council meeting. It also placed the change in method of mailing the ballot into effect for this year's election. The other changes will go into effect as of 1 January 1958.

In addition to the recently adopted changes, the new printing of the By-laws incorporates some previous changes such as the provision for Junior Membership. It had not been considered desirable, for reasons of economy, to reprint the By-laws each time a change was made.

It may be of interest, that the total cost of the balloting, printing and distribution of these By-laws will run about $1000. Thus about 35 cents out of the first year's increased dues for each member will be spent to effect the change.

Annual Budget

For several years the Society has operated at a loss. This was done advisedly by the Council while changes in the JOURNAL, Society offices and general increase in costs of everything were being allowed to straighten themselves out. In the 12 years since 1945 the net worth of the Society has declined about $30,000. We have now reached the point where a halt must be called. Our present net worth is about equal to one year's gross expenditures.

The principal reason for increasing the dues was to halt the inroads into capital without appreciably reducing returns to members which are principally in the value of the JOURNAL. Unless there is a healthy growth in membership and some increase in advertising revenue to offset an expected continuing gradual rise in prices, these latter will have to be met by economies in the JOURNAL.

One recent change in the By-laws is the requirement that the Society operate on a firm budget. This will be done during 1958. In connection with this budget and the increase in dues, the Council has established as a policy:

> The budget will be designed and adhered to, to insure no loss each year.
>
> As necessary this will affect the size in contents of the JOURNAL.
>
> For the foreseeable future, increased prices will be met by proper budgeting and an increase in dues will not be used to offset a weakening dollar.

Long-Time Members

We recently had the pleasure of a visit at the Society office by Captain Albert Norris, U.S. Navy, retired. Captain Norris has been a loyal member of the Society since 1905.

This visit alerted us to a neglect. Not since 1952 have we published a list of those members who have been on the rolls for 50 or more years. At this time these are those few who for half a century or more have maintained their membership:

Name		Date of Membership Entry	Length
Dinger, H. C.	Naval Member	1903	54 years
Gregory, Henderson B.	Civil Member	1902	55 years
Kibbee, Austin S.	Naval Member	1907	50 years
Maccoun, W. E.	Naval Member	1902	55 years
Norris, Albert	Naval Member	1905	52 years
Powelson, W. V. N.	Naval Member	1904	53 years
Turner, J. B.	Naval Member	1903	54 years

The following have been members for 45 years or more:

Anderson, Ernest H. B.	Civil Member	1908	49 years
Bagger, F. E.	Naval Member	1911	46 years
Beck, S. H.	Associate Member	1911	46 years
Cairnes, George S.	Naval Member	1908	49 years
Charlton, A. M.	Naval Member	1912	45 years
Cook, F. A.	Naval Member	1911	46 years
Doyle, M. A.	Naval Member	1909	48 years
Johnson, C. H.	Naval Member	1911	46 years
Loeb, Leo	Associate Member	1912	45 years
Lord Weir of Eastwood	Associate Member	1910	47 years
Metten, J. F.	Civil Member	1910	47 years
Thayer, H. H.	Civil Member	1912	45 years
Woodward, Clark H.	Naval Member	1910	47 years
Yeager, T. H.	Naval Member	1910	47 years

New Employee:

On 30 September, 1957, Miss Ruth Leonard joined the staff as bookkeeper. She joins Mrs. Virginia Burns who has been with us since March 1957 and Mr. Fessendon who has started his fiftieth year as the backbone of the Society.

Annual Banquet:

The 1958 banquet of the Society will be held at the Statler Hotel, Washington, D.C., on Friday, 2 May, 1958. As in 1957, one non-member guest will be permitted for each *two members who attend.*

Vice Admiral Earle W. Mills, USN, Ret., Chairman of the Board and President of the Foster-Wheeler Corp., President of the Society in 1945, has accepted the President's (Admiral Mumma's) invitation to be the principal speaker. We had looked forward to having Admiral Mills last year, but he was forced to withdraw when business took him out of the country at the time of the banquet. We are fortunate that he has again accepted with the assurance that this time the engagement will not be interfered with.

Society Award Questionnaire

Too late we discovered that the printer (and we in proofreading) had made an omission in the questionnaire which was designed to collect a concensus of members in regard to the proposed award. The third question should have had a part (c) which would have made it quite clear that neither the Council nor the Committee held a preconception of limiting an award to Naval Members. At the present time there is an absolutely open mind as to

(a) Whether an award shall be made.
(b) What eligibility rules shall be adopted.
(c) The criteria for selecting the awards.

Whether or not members have sent in the questionnaire, any additional comment or suggestions will be very welcome.

Basic Research—A National Resource

In the book review section of this JOURNAL, is a notice of a publication entitled "Basic Research—A National Resource." This pamphlet sets forth the views of The National Science Foundation as to the importance of increased support, for basic research in the sciences, from private and public sources. It should certainly be of great interest to every citizen and of special interest to members of this Society. The Naval Engineering profession, during the life of the Society, has participated in the practical application of the fruits of basic research to an extent realized by few other professions. At the moment some idea of this may be gained by comparing the picture below and the one on pages 616 and 652 with the White Fleet which carried the National Ensign in 1888 when the Society was formed. Advanced, in comparison, as today's concepts are, certainly no Naval Engineer is ready to rest on his oars. Only as more basic knowledge is gained in the sciences will the inventors and engineers be able to carry on with success comparable to that of the last three generations.

Artist's concept of the guided missile frigate in the 1958 shipbuilding program. This ship is the first full transition from guns to missiles as the primary armament. A notable feature is the upper deck extending to about the after quarter point. Also noteworthy is the combined mast and stack.

ADMIRAL S. M. ROBINSON

EMPTY SPACE

THE AUTHOR

is one of the most prominent agents of progress *in Naval Engineering. He has made many contributions to the Journal. He was intimately associated with the development and adoption of electric drive for Naval capital ships in his earlier days as an Engineering Duty Officer. After successfully reaching the top in his field—Chief of the Bureau of Engineering and Engineer-in-Chief of the Navy he was chosen for new "tops" as they were created, becoming the* first *Chief of the Bureau of Ships and the* first *Chief of Naval Material (then known as Office of Procurement and Material). These two highest positions he occupied during World War II and they sorely tried his talents as an administrator and coordinator of diverse military and civilian interests. Both jobs were "Well Done" and Admiral Robinson retired with the rank of full Admiral, never previously attained by an EDO. Admiral Robinson was appointed Secretary-Treasurer of the Society in 1921 and was elected for 1922 and reelected for 1923. He was elected President in 1931 and again in 1939.*

MY PURPOSE IN presenting this paper is to stimulate interest on the part of some Foundation, Philanthropist, or Organization in this subject so that there will be established a laboratory for the sole purpose of investigating the properties of so-called empty space. I believe this is the quickest and probably the only way in which any real progress can be achieved in this investigation. To convince anyone of the advantages of a one-purpose laboratory, it is only necessary to cite the case of Lord Rutherford in his investigation of the atom. The progress made by this laboratory, which attracted scientists from all over the world, was truly phenomenal. Other people are convinced of the correctness of this method as is shown by the number of these laboratories now in existence and the number is growing. Probably the most important of these is one set up by Dr. Kettering for the investigation of photosynthesis.

A number of scientists have stated that they do not expect another such period of scientific progress and discovery as we have experienced in the last fifty years. Some even go so far as to intimate that they believe we have about approached the limit of our ability to penetrate the secrets of nature. I believe this is partly based on a misconception of what we have already accomplished. Actually this is very little so far as fundamental knowledge is concerned. We have become hypnotized by the fact that our mathematics has been developed to the point where we can predict almost any event but without really knowing anything about the event itself. History shows that the progress in the knowledge of science has been made in jumps and not as a steady development. It is difficult to discuss the most recent developments without being misunderstood. I do not believe anyone would wish to disparage or in any way minimize the accomplishments of the last fifty years. Mathematical formulae have been built up to cover almost all reactions in physics and chemistry. These have enabled us to make progress not even dreamed of fifty years ago. The most spectacular of these is of course the atom bomb but the advancement of our civilization is much more important. We live in a new world and with a standard of living which is fantastic compared with that of a hundred years ago. But when we get down to the fundamentals of physics we have actually made almost no progress. We still do not know what electricity, magnetism, gravity, radiation, etc. are. We know all about what they can do; we can predict very accurately the results from any given set of conditions and we have persuaded ourselves that we really know what these things are. We talk very glibly about fields and wave-mechanics and differences of potential and infinity and we have convinced ourselves that these are realities. Take for example the idea of infinity. Any student will handle equations involving infinity with the same aplomb that he does any other alge-

braic equations; he will even give you a definition of it but it will not mean anything.

Now it seems to me that the time has arrived to make an effort to pierce this stone wall. And it also seems to me that the most promising place to begin this search is with empty space. Since this enters into practically every problem that we want to solve it should be obvious that here is where we should spend most of our energy instead of trying to solve problems which require a knowledge of the properties of empty space.

It has not been so many years since we were content with our conception of empty space. We simply filled it with an ether which had the most remarkable properties that any substance, real or imaginary, has ever had. It took care of all of our problems concerning "action at a distance," such as gravity, fields, radiation, etc. The mere fact that we had postulated such a substance showed how necessary we considered it to be. When Michelsen, with his famous experiments on the velocity of light upset the ether theory, the scientists were temporarily left at loose ends but the mathematicians soon came to their rescue, especially with the wave-mechanics formulae for taking care of radiation which seemed to be the most difficult problem. I have often wondered why no one seemed to think it important enough even to try to find a substitute for our friend the ether. It is interesting to refer to the comments of the distinguished scientist, Sir James Jeans, which were made at the time of the experiment. In effect, he said that Michelsen had not really abolished the ether but had only temporarily rendered it unnecessary and that if we needed it later it would be brought out again. To use a modern slang expression, it had been placed "in mothballs." Now I do not suppose for an instant that Sir James had the slightest idea that the old form of ether would ever return but he did indicate that he was not at all satisfied with the cavalier way in which scientists had dodged the issue on this very important problem. I think the reason for this situation is not difficult to find. Scientists were in a hurry and they did not propose to be held up for years searching for a substitute for the ether and events have proved they were right—to a point. The progress we have made justifies the decision but it is unfortunate, very unfortunate, that no one had the foresight to carry on the other investigation at the same time. Had they done so we would probably not be confronted with the stone wall that physicists are now envisioning.

As an example of where we now stand let us consider for a moment the situation of our astrophysicists. For a long time they have been debating the past and future of our universe—especially its age, method of formation, its final end, and many other things. I think most everyone will agree that none of the theories proposed concerning these things have been satisfactory. The truth is that new facts coming in overturn these theories almost before they have been completely formulated. To cite only one example, the discovery of the "expanding universe" was almost as disastrous to existing theories as Michelsen's experiment was to the ether. The difficulty with all these theories was that they assumed that there had to be a definite beginning and a definite end to the universe. Not all scientists have subscribed to this theory as is shown by the fact that numerous attempts have been made to find a "winding up" process to counteract the "running down" process that is so universally accepted. This is to me the most difficult thing to understand in all the history of science. Why it should never have occurred to anyone that the universe had always been here and always would be here will remain one of the greatest mysteries of all time. And an almost equally great mystery is why there was such a furore when a young British scientist, Fred Hoyle. stated that matter was being continuously created and that the universe would keep right on going just as it always had. The thing that seemed to upset the older scientists was this apparent creation of something out of nothing. The first reaction was that of amusement with a tendency to simply brush it off. But it would not brush off and recently there have been very serious attempts to discredit the theory. One of the older British scientists waxed hysterical and practically accused Mr. Hoyle of being a charlatan seeking publicity. While all scientists accept the fact that the vast amount of matter in the universe had to be created at some time or other, there seems to be a tendency to do it all in one fell swoop and get it over with. I believe this is the greatest example of "swallowing the camel and boggling at the gnat" that history has produced to date. The rate of creation proposed by Mr. Hoyle is so infinitesimally small that even the gnat is entirely too large for the comparison—a virus would probably be better. Now there is no escape from this dilemma. Unless we are willing to argue that the laws of nature have been changed, we must admit that if empty space once had the ability to create matter, then it must still have it. The only surprising thing about the whole business is the length of time it has taken for someone to discover a perfectly obvious fact. This is one theory that requires no proof as it as definite a fact as that there is anything as definite as matter. A lot of questions can be asked as to why this creation comes about. Also what it is that triggers off this reaction in empty space. We might also ask what triggers off the action of radioactive material. Of course we do not know but so far no one has thought to question the fact. So far as I know no one has even ventured a theory as to how this reaction is brought about. The point I am trying to stress is that it is time we tackled some of the fundamentals of physics instead of dealing solely with end results, interesting and useful though they may be.

This all does lead to the definite conclusion that there is no such thing as empty space in the sense that we ordinarily use that term. Well what could it contain? There is one answer that will probably

occur to all of us. Of all the work done by Einstein, I think we will all agree that it was his proof of the equivalence of matter and energy that was the most important. It is only a step from this fact to the assumption that empty space contains an infinite amount of potential energy and that an infinitely small amount of this is being regularly triggered off to be converted into matter. This theory would also solve all questions of "action at a distance." No one seemed to be upset when Einstein resorted to the warping of empty space by the presence of matter in order to explain the action of gravity. Well anything that can be warped must certainly have properties that are not ordinarily assigned to empty space. Again it is a case of the camel and the gnat. In reading the criticisms of Dr. Hoyle's theory I have the feeling that his critics seem to fear they are being asked to subscribe to witchcraft. I would like to remind them of the history of the Theory of Evolution. Every effort was made to avoid the resort to the use of unknown quantities or actions to bring about an orderly process of evolution. But it simply could not be done. Jumps took place in the process which could not be accounted for by any of the existing theories so a very quiet admission was made that some completely unknown factor was responsible for these jumps. This admission made no great stir in the world of science; why then should we be so upset about the creation of matter, especially when it is so much more obvious than any of the other "camels" which we have swallowed without having indigestion.

And now whether I have made any progress in furthering the theory of the continuous creation of matter or not, I hope I have made a case for setting up a laboratory to investigate the properities of empty space. The many difficulties connected with such a proposition are so obvious that it is unnecessary to list them. It is clear that such research can only be done by indirect methods but that it should not be a deterrent since most research is carried on that way at present. Take for example the case of the neutrino—a particle without electric charge or mass; at the time its existence was predicted, it was predicted that it would be impossible to prove its existence and yet it has recently been accomplished by a group of scientists by indirect method. The possibilities in this case are so great that I feel sure it will be undertaken and when we solve this riddle, I predict that we shall have to rewrite all of our physics books. I doubt if any of our present theories will remain completely unaffected.

Radio astronomy, a science born in 1931 and attracting scant interest until 1945, has grown to new proportions in the past twelve years. One of the most recent investments to further the science is the construction of a giant radio-telescope at Jodrell Bank in England. The telescope will have a parabolic reflector with an effective diameter of 250 feet. The instrument can be moved to point in any direction in the hemisphere. With its extremely high discrimination, the telescope will be able to map radio sources in detail.

—from "Electronic Engineering," September 1957

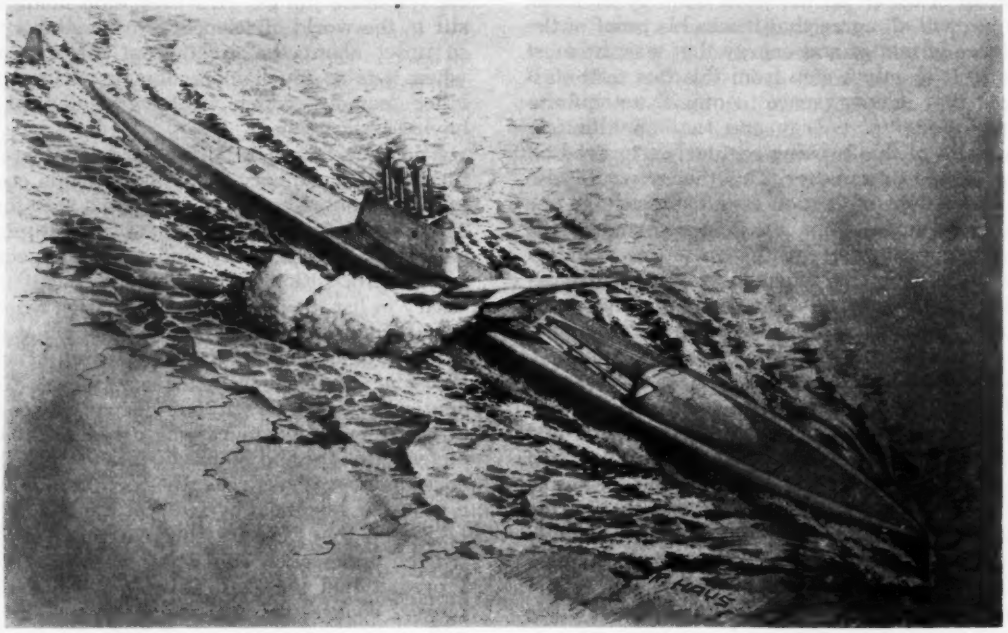


Figure 1 (above). Artist's Conception (SSGN-587).

—Official U.S. Navy Photograph

Figure 2 (right). Third A-Sub leaves atomic teammates—the Nation's third atomic submarine, *Skate*, entered the waters of the Thames River on May 16, 1957, at the Groton, Conn. shipyard of General Dynamics Corporation's Electric Boat Division, leaving behind its nuclear companions, *Skipjack* (left), fastest atom sub, and *Triton* (right), largest member of the Navy's future atomic fleet. *Skate*, the first production model nuclear submarine, was christened at exactly 12:30 p.m. by Mrs. Lewis L. Strauss, wife of the chairman of the Atomic Energy Commission.

—Official U.S. Navy Photograph

J. LEWIS POWELL

THE COLLAPSE OF TIME

THE AUTHOR

is on the staff of the Assistant Secretary of Defense (Supply & Logistics). His principal responsibility is monitoring the Industrial Mobilization Planning. This activity deals with the principal means by which the Army, Navy, and Air Force plan with American industry for the production of military items in the event of war. Mr. Powell is a graduate mechanical and aeronautical engineer, and has worked both in private industry and in the government. During World War II, he served first as a civilian with the War Production Board, and later as a Naval Officer attached to the executive office of the Secretary of the Navy. In both assignments he did management trouble-shooting in the field of industrial mobilization, on a nationwide basis. Shortly after the outbreak of Korea, Mr. Powell was recalled to Washington to again work in the field of industrial mobilization. He is active in the Naval Reserve, holding the rank of Commander. Mr. Powell is a nationally recognized authority in the field of industrial mobilization, and is known both as a speaker and writer. Mr. Powell is the author of the following articles: "Battle Stations for Industry," "Gearing Industry to National Defense," "The Hook-Up for Industrial Logistics," "Stockpiling Know-How," "Stampede of Progress." *During the past year, Mr. Powell has been a principal speaker at numerous industrial meetings throughout the United States. He is best known for this dynamic talk which was presented at the annual meeting of The American Gear Manufacturers Association at Hot Springs, Arkansas, on 3 June 1957.*

ONE THOUSAND dollars plus per second or about 100 million dollars a day is what this nation spends for defense. This is the premium for preparedness, based on the direct military budget alone. A community supports a fire department because it realizes that there is no completely fool-proof method of fire prevention. Accidents and arsonists are realities that must be recognized.

Political uprisings and dictators are realities, too. These can cause wars, hence the need to support an Army, Navy, and Air Force.

Just as we consider the cost of a fire insurance premium, let's consider the cost of preparedness—or war prevention premiums. And, because of time, let's limit our discussion to the industrial facet of this problem.

Usually this subject is dismissed with the platitude that war has gone technological. Just what do we mean when we say war has gone technological? Let's consider some specific examples:

Sir Lancelot's armor weighed 84 pounds, but the gear of a jet fighter pilot weighs 144 pounds.

The size and weight of a B-17 bomber was pretty impressive during World War II. Today, this weight represents the fuel load of a modern jet bomber.

More flight testing must be done on a single B-52 than was done on all the B-17s ever built.

(Extract, Washington Briefing,
Aviation Age, 17 October 1956)

We used to buy a World War II plane for $50,000. Today, a jet engine overhaul can cost that much.

The S. S. *United States* and the S. S. *America* are the two largest American Merchant Marine ships afloat. Yet, they both could be placed side-by-side on the flight deck of a *Forrestal* class carrier. The Empire State Building is about as high as the *Forrestal* is long, and few cities can boast of buildings taller than the *Forrestal* (25 stories).

While war has been going technological, let's consider where technology has been going. Technology has stampeded, it won't stand still long enough for war to catch up.

Let's graph progress. We will plot the "Curve of Technology" down through the ages. A good index of man's progress is speed, the speed at which man can travel. So, let's plot "speed" from 1500 years before Nero 'till now.

In Nero's time, or even for 1500 years before that, man could travel only as fast as a horse could carry him.

I understand that quite a few members of this audience are scientists, in fact, I understand that a number of you have very generously contributed your personal time and money to the study of the speed of horses.

Other scientific friends of mine who have done extensive independent research on the speed of horses at such places as Bowie, Pimlico, Churchill Downs, and other institutions of higher learning, sadly assure me that the speed of a horse is in the neighborhood of 30 to 34 miles per hour.

In 1500 B.C., or 15 centuries later, when Rome burned—or thirty centuries later, when Columbus discovered America, the speed at which man could travel was still limited to the speed of a horse. Two centuries later when Paul Revere made Longfellow famous, he was dependent on Dobbin. So, on our graph we would have a straight line from 1500 B.C. to about 1830. More than thirty centuries and no progress.

In 1830 a tremendous historical event happened. "MAN BROKE THE OAT BARRIER." After centuries of scientific stalemate, the "Iron Horse" broke the "OAT BARRIER," mankind was liberated from the athletic prowess of horses as a means of transportation, the technology of transportation was born.

Progress plodded forward. In 1910, our first military airplane had a guaranteed speed of 42 miles per hour. Thirty-five years and two wars later, persistence had pushed speed up to 470 miles per hour. It took man more than a third of a century to go from 42 to 470 miles per hour.

In 1945 progress changed its pace, it stampeded! Although it had taken 35 years to go from 42 to 470 miles an hour, in the decade from 1945 to 1955 man catapulted speed from 470 miles per hour to more than 1500 miles per hour. New records every few days—progress that formerly took years now takes weeks. Progress itself has become a technical product that can be systematically produced by the technique of applying mobilized brainpower to specific problems. The plodding progress which had characterized the first industrial revolution has been replaced by the synchronized research of organized science.

Our curve which ran dead level for more than thirty centuries curved gently upward with an increasing slope from 1830 to 1945. Then, in 1945 it careened around a corner and shoots skyward. The horizontal line has gone almost vertical. The superaccelerated progress of each recent year exceeds the progress of previous centuries. The stampede of progress as shown by the graph of speed was dramatically climaxed over Long Island on 21 September 1956 when a Navy plane shot itself down by overtaking and colliding with its own bullets.

Just as geologists now systematically locate oil and mineral deposits by scientific technique of controlled exploration, man now engineers progress by applied techniques of research and development.

This curve has been called "The Collapse of Time." Time is no longer the major ingredient in progress. You can forget that we plotted this curve for speed and you can substitute missiles, explosives, or medicine. The results are always the same.

A few quick examples—In missiles let's plot from David's slingshot to the Roman catapult to the present headlines about intercontinental missiles, or plot explosives over centuries. They increased a few times in effectiveness. Yet, within the last few years, they have increased millions of times, so much that we had to invent a new word to even measure them —the word "Megaton." The biggest explosive we had in the European Theater in World War II was a blockbuster—a value of six tons of T.N.T. Now, we measure modern devices in megatons. One megaton is equal to a million tons of T.N.T. (166,000 blockbusters). It would take a freight train stretching from New York to Washington merely to carry a megaton of T.N.T.

That little ole primitive job that was dropped on Hiroshima was rated at 20 kilotons or one-fiftieth of a megaton. To sum up—where has technology gone? In the words of our teenagers, it's gone, REAL GONE. It's skyrocketing—zooming out of this world.

Let's look at technology from a strictly civilian viewpoint. If you go to get a prescription filled at the druggist, the chances are seven out of ten that the medicine you get was unknown fifteen years ago. Today, 170 million Americans thrive on the same land, where one million Indians starved from one famine to another. We have 7,000 more people for breakfast every morning. Yet, with all this increase, we are the only nation on earth where you have to beat your kids to make them eat.

Half the world goes to bed hungry every night, yet our only problem is surplus. We have the same land and the same resources that the Indians had, but we have something else—trained minds, skilled manpower, and tools. These are the priceless ingredients of technology.

Mix technology and democracy and you produce a standard of living and political freedom that makes the dreams of Utopian thinkers seem like the product of backward imaginations.

Just as we exploit technology for peace and prosperity, we must also exploit it for national defense. Technology has no morals, it is not limited to America, it doesn't care who uses it. It works with equal impersonal efficiency and grim effectiveness for good or evil, for friend or for foe. This is the reality of the age in which we live.

Modern war, whether cold, hot, or lukewarm, is a head-on clash of total economies, total national resources, men, machines and materials. For this reason, military preparedness can be no better than the industrial readiness which backs it up. Military preparedness and industrial readiness are heads and

tails on the same coin, they both must be geared to the ever-changing technology of this age.

Before we proceed to consider the mobilization of a complex economy, let's pause to pay homage to the mobilization of a simple economy. For example, when Italy invaded Ethiopia, Haile Selassie is reputed to have mobilized his country this way:

"The country is now mobilized. All men and boys able to carry a spear will report immediately to Addis Ababa for active duty. Married men will bring their wives to do the cooking. Women with babies, the very old, and the very young, need not report for active service. Men that are not married will bring any woman they can find. Anyone else found at home after the issuance of this order will be hanged."

Mobilizing the United States is more complicated because we have a more complex economy.

Our mobilization needs break down into three general categories:

1. *Essential Civilian Requirements.* These are the absolute necessities to keep your economy functioning. These are the materials for water supply, sewage disposal, fire-fighting, police protection, hospitals, food, clothing, and shelter.
2. *Defense Supporting Requirements.* These are the things necessary to maintain your industrial economy so that it can produce military items. For example, freight transportation, communications, repair, maintenance, operating supplies, raw materials, electric power.
3. *Direct Defense Requirements.* These are the guns, planes, tanks, ships, ammunition, missiles, etc., that are used directly by the Army, Navy, and Air Force.

These last, the Direct Defense Requirements, are the ones with which we are primarily concerned at this meeting. However, before I proceed, I want to emphasize that all three kinds of requirements are essential to the pattern of preparedness. They are the legs of the tripod on which the mobilization base rests. Which leg is the most important? Get one leg out of adjustment and a tripod collapses. Mobilization is the art of synchronizing the legs of a political, economic, and industrial centipede.

The Business and Defense Services Administration of the Department of Commerce is primarily concerned with Essential Civilian and Defense Supporting items, while the Department of Defense is responsible for planning for Direct Defense items. These programs do not compete with each other. They are both part of the pattern of preparedness. They do not conflict anymore than heads conflicts with tails on the same coin, one is no more important than another. They are like the length and width of a square, they compliment each other.

Being a democracy, we have no munitions industry. The United States has a civilian industry that makes peacetime products for the American way of life. When war comes, we have to mobilize our civilian industry for war, just as we mobilize our resources for any other disaster. For example, in your city, you don't have a water supply system exclusively for fighting fires. What you have is a domestic water supply system for routine daily use. But! When a fire breaks out, your fire company hooks into fire plugs and instantly converts that water supply system to fire fighting.

We do the same thing when war comes. We hook into our civilian production lines and convert them to war production. Just as you have a fire plug to expedite the conversion of your water supply, so you have mobilization planning to expedite the conversion from peace production to war production.

World War II demonstrated the need for better planning. Let's review our mobilization history.

We started World War II with the most gigantic game of hide-and-seek on record. Everybody was it. Thousands of industrialists descended on Washington to find out who in the military bought what. At the same time thousands of military men scoured the country trying to find out who could make what. It boiled down to this—if you wanted to buy a land mine you couldn't look up that manufacturer in the Yellow Pages of your phone book. The man who could make a land mine didn't know what a land mine was, let alone know he could make it.

Two of the principal products we produced were "Surpluses and Shortages." We had ships without engines, planes without propellers, tanks without transmissions. Our overall effort was well summarized by Winston Churchill, who said:

"First year one drop
Second year a dribble
Third year a deluge"

It is elementary, therefore, that if we are not going to have a big game of hide-and-seek next time, we had better match up our military producers and our military requirements now. For sustained readiness:

The military must always know
who can make what
how much can he make
how fast
Industry must always know
what military agency wants what
how much
how soon

The stampeding technology has erased the security which formerly was stored in stockpiles. According to history books Revolutionary War muskets were used in Civil War, and World War I equipment served in the early days of World War II. Today's modern complex weapons have an infinitely shorter life span. The plane coming off the production line is obsolete compared to the one coming off the drawing board. There is no longer any continuity of technology between wars. Each war involves a radically new technology, and not much security can be gained from stockpiling awesome quantities of specific military mechanisms that become hopelessly obsolete faster than they can be replaced. Instead, it is vital that we maintain minimum stockpiles but keep them updated and geared to progress in technological developments.

These stockpiles of updated weapons must be continuously backed up by maximum industrial readiness to replace them with still later models.

In event of war, planning is an insurance policy with a double pay-off. It insures strong national defense and at the same time it insures the continuity of your production.

Matching specific potential military customers to individual potential producers is the basic step in mobilization planning. The program for doing it is the Revised Production Allocation Program.

Here's how it works. The basic concept is similar to the Navy principle of "Battle Stations." On shipboard at all times every sailor knows what he is expected to do in an emergency. He not only knows it, but he has always known it—it's his Battle Station.

The Production Allocation Program gives "Battle Stations to Industry." By matching up actual military production schedules with specific planned producers, this planning gives these plants their "Industrial Battle Stations."

By having the military and industry sit down together and do across-the-table planning in peacetime, the buyer and seller discover each other now. In event of war, this would:

1. Eliminate wartime hide-and-seek;
2. Spread the mobilization impact more evenly across our capacity; and
3. Get better utilization of each plant since management has an opportunity to plan the use of its own plant.

Primarily, our planning is with prime contractors who fabricate items which meet the following criteria. The end use must be:

Survival and retaliation.
Increased combat efficiency.
Maintenance of health.

Planning for items of comfort, convenience, and morale is prohibited, while planning for about 500 items on a classified Preferential Planning List is mandatory.

To talk intelligently about planning we need to talk about two things—one called an ASPPO—the other called a Register.

It is quite important that you understand who and what an Armed Services Procurement Planning Officer, or ASPPO, is. If we had the Army, Navy, and Air Force, including all their branches, planning at will, with every plant, industrial management would be run ragged answering the same questions over and over again for each service. Similarly, the services would be competing with each other with conflicting claims for the same capacity. To prevent this we assign an ASPPO for each plant. His job is to represent all of the Armed Forces and act for the Assistant Secretary of Defense in coordinating all the military planning with that plant. Anyone wanting to plan with your company must funnel his request through your ASPPO.

There are two things you should do with your ASPPO:

1. Help him make a good informative survey of your plant.
2. Build your production know-how into mobilization production schedules before you sign them.

Remember these stockpiled production schedules are industrial "Battle Stations."

You and your ASPPO have a job to do. It is your job to balance military mobilization requirements against production capacity. It is up to you to work out the best compromise between military logistic requirements and your plant capacity. Our planning is only as good as you and your ASPPO make it.

Our quality control is the competence and integrity of the military industrial team who produce our mobilization production schedules. Its up to the military to contribute logistic savvy—management supplies the production "know-how."

What is the mobilization line-up? Who plans with whom? Periodically, the Department of Defense publishes a book called the Register of Planned Mobilization Producers (RPMP). This Register lists the 21,000 plants with whom we are planning and it cross-references each plant listed to the military departments that are planning with it.

Every entry in the Register advertises to all Army, Navy, and Air Force procurement planning officers that that particular producer is interested in planning for wartime production. For each plant listed it also shows who is the Armed Services Procurement Planning Officer (ASPPO).

This Register is geared to change. Periodically, we purge the Register of dead-head entries; ones with whom planning has never materialized or those who want to write their own rules.

Although the Register is a classified document, every manufacturer is entitled to see his own entry, or to be told he is not registered. This information can be obtained from the nearest Army, Navy, or Air Force procurement office.

If you are registered, here is what you should do:

1. See if your plant survey is up-to-date.
2. See if your mobilization schedules are current.
3. See if you're over-planned or under-planned.
4. Contact potential military customers—sell them on your ability.

If you are not listed in the Register:

1. Determine if your production potential qualifies you to be a planned producer.
2. Identify and locate your potential military customers.
3. Sell your potential customers on your know-how and ability just as you would sell any other customer.

Let's look at the "Curve of Technology" again. Since technology won't stand still, mobilization planning in this day and age might be compared to changing a front tire on a speeding automobile while it's racing down a winding country lane. Preparedness cannot be static. Strategy, tactics, production, and even planning itself must all be continuously revised to keep them reconciled with the reality of our ever-changing technology and our more complex weapons.

The newer a weapon is the more complex it is. (Compare the bow and arrow versus the machine gun.) Similarly, the more complex the weapon or device the shorter its life-span. (Consider the life span of the B-29 compared to the battleship, or the

life span of a radio compared to the 10 inch television.)

Each newer more complex device is even more rapidly replaced by a still newer even more complex device.

These truisms of technology give Uncle Sam a problem similar to the dilemma of a one-armed man on a flying trapeze. He has to let go of the ordnance and equipment of yesterday, yet the weapons of the future have not yet swung completely within reach. This is the period for decision.

We have to occupy space that is beyond hand-grenade thinking on one extreme, and not yet up to Buck Rogers on the other. Remember when you were a kid in school if a problem didn't come out even, you knew it was a wrong answer. Well, in this business, there are no easy answers that come out even.

Today's war, whenever today may occur, would have to be fought with today's weapons. It could be lost with either the obsolete weapons of yesterday, or the as yet untried theoretical weapons of tomorrow.

We always delude ourselves into thinking new facts are just new ideas about old facts. Remember the people who said the airplane was merely a better reconnaissance device, or tanks merely mechanized cavalry? They were mentally sabotaged by semantics.

Consider heritage from the days of the bow and arrow, when someone first uttered that pious platitude "that for every method of offense there is a method of defense." He forgot to add the word "eventually!"

In those days no one invented new weapons until a defense method defeated the previous weapon. Time was then measured in months, years. Today, time is measured in flying hours. Similarly, the concept "intercontinental" has become a term of reference for the range of missiles. Yet, the full realization of nuclear weapons is debated by our retention of the obsolete word "bomb." To refer to a nuclear weapon as a bomb is like calling a machine gun a rapid-fire, improved automatic bow and arrow. The appropriate descriptive term of reference for nuclear device has yet to be invented. Man's technology has out-distanced both his language and his imagination.

The electronic wonder of today like today's newspaper will be obsolete tomorrow. Similarly, today's preparedness won't meet tomorrow's problems.

We have always been prepared—always prepared to fight the last war over again. Remember the cavalry we had ready for World War I—1,000,000 horse blankets—2,000,000 feed bags; or our air force at the outbreak of World War II, it would have looked good in World War I. (We still haven't disposed of the horse. No one has yet made a statue of a general mounted on a jeep.)

Preparedness is an age of onrushing technology. It is like running the wrong way on a moving stairs. You have to go like the devil to stand still.

Someone always asks the Sunday Supplement Question—"Are we preparing for the long war or the short war?" Ask your fire department if they are planning a big fire or a little one.

Democracies don't plan wars anymore than fire departments plan fires. Just as a fire department has plans to meet the possible kinds of fire that might break out, we plan to meet the kinds of war which might erupt. Just as the fire department hopes never to have a fire, we just as fervently hope there will never be a war.

Since democracies don't start wars, the enemy automatically has the advantage of deciding where, when, and how war will start.

Those considerations have much to do with the probable length of any war. Obviously, if we elected to be thoroughly prepared for one kind of war, at the expense of being unprepared for other kinds—any intelligent enemy would elect to start the kind for which we were the least prepared.

Therefore, our planning must be flexible enough to meet the reality of the time, place, and method chosen by the enemy.

Planning is somewhat like insurance. There are different viewpoints on the subject. Some people don't believe in insurance and some don't believe in planning. Maybe they are the same people.

Usually, you get three arguments against planning:

1. *One* goes like this—Any new war would be over overnight, so why plan? This is like saying that there is no use studying first aid because if you get in an accident you are bound to be killed. In event of violent war, victory may well go to the side which can first stagger back to its feet and deliver the second blow.

2. Another argument against planning goes like this—We didn't use all of our plans for World War II or Korea, so why plan now? This is the logic which says we didn't use all of our fire plugs in the last two fires, so why have fire plugs?

3. The third argument goes like this—Planning is good but you shouldn't do it until you know your exact quantities of tanks, planes, ships, weapons, etc. This is the logic, which says fire plugs are wonderful but don't install them, until you know how much water it takes to put out a fire of unknown origin at an unknown time in an undetermined location.

If you won't buy that kind of reasoning on fire protection, don't buy it for national defense.

Preparedness makes for defense. For example, there were more than 50,000 holdups in the United States last year. In no case did a bandit hold up a policeman. The known preparedness of a policeman is a deterrent. Similarly, a marauding nation hesitates to invite its own downfall by attacking a nation known to be capable of destroying its attacker. In both cases, publicized preparedness makes "Defense" the powerful deterrent.

How does the stampede of progress affect planning? Well, if you are five years behind the times in your thinking now, you are further behind the times than your father would have been if he were 25 to 50 years behind in his thinking.

We are faced with the possibilities of the long war, the short war, the quick war, and the slow war. How do you get prepared to fight the long, short, quick, and slow war?

Modern weapons do not give time enough for obsolete thinking—we must outsmart potential enemies by unleashing our fettered imaginations. We must think in terms of the accelerating technological age in which we live.

According to Aircraft Industries or Reader's Digest—take your pick—one modern nuclear device can unleash more fire power in one single explosion than all the bombs we dropped in Germany and Japan together during World War II.

Quoting from January 1956 issue of Reader's Digest, "Inside the H-Bomb Plant," by Henry J. Taylor:

The first output was tested near Eniwetok atoll in the Pacific on November 1, 1952. That bomb was called "Mike." It was too big to be dropped from an airplane. It wiped out the the island of Elugelab, on which it was shot, leaving in its place a crater 175 feet deep and a mile wide—big enough to hold 14 Pentagon buildings.

That single bomb had more force than the combined weight of all the bombs dropped on Germany and Japan throughout World War II.

In 1954 another H-bomb, by now so developed that it could be airborne, was exploded in the Pacific. It produced several-fold the force of the first one.

Aircraft Industries Association:

One modern U.S. bomber, with a crew of only three can carry more destructive power in one mission than the combined air forces of all combatants could carry in World War II.

Remember, it took man 250 years to progress from the "short bow" to the "long bow," yet it took less than ten years to go from the A-bomb to the H-device. Under these conditions, industry and defense are inseparable. Military preparedness is inextricably geared to industrial readiness. Our national strength rests on the sound foundation of an alert, capable military industry team.

I wish to express our appreciation for this opportunity to discuss these problems with you. Frankly, we have a selfish motive in talking to audiences like this. You have something we want. It is your brains, your initiative, your imagination and your know-how which we need to store in the Arsenal of Democracy. Gentlemen! It is you, the American Executives, who are our "Vice Presidents in Charge of Tomorrow." This is our problem, what do you recommend?

Although Project Vanguard and Antarctic work have received greater publicity, the U.S. Navy is sponsoring other important work in connection with the International Geophysical Year. Rocket-balloon firings to obtain data for cosmic ray studies are scheduled in several parts of the world. Instrumented rockets will obtain data on solar radiation, atmospheric composition and ionospheric current flows. Oceanographic research will be carried out in connection with studies of currents, interrelationship of phenomena of the ocean and atmospheric conditions, and submarine mapping.

—from "ONR Research Reviews," August 1957

"ENGINEERING"

PROSPECT FOR DOUNREAY—MAKING THE MOST OF NUCLEAR FUELS

ACKNOWLEDGEMENT

This reprint consists of a staff write-up appearing in the May 17, May 24 and June 7, 1957 issues of "Engineering."

A COUNTRY without direct access to nuclear fuels must take great care to use the limited quantities at its disposal to best advantage. To consider the technical aspects of this problem, the United Kingdom Atomic Energy Authority has set up an establishment at Dounreay in the North of Scotland, where a number of studies are already in progress. Dounreay is particularly noted as the site of Britain's first power-producing fast breeder reactor, the containment sphere for which is already a familiar picture. This project by no means exhausts the activities of the establishment, and a materials testing reactor and other facilities are also under construction. In addition, the Authority is providing a site and foundations for the land-based prototype of the Admiralty's submarine reactor. But in a broad sense the entire work of Dounreay may be regarded as devoted to the economic use of nuclear fuels, from efficient chemical processing and fuel fabrication to the breeding of fissile materials. It is a project of great significance, not only for Britain, but for the whole Continent of Europe.

Natural uranium comprises only one part in 140 of uranium 235, the fissile isotope capable of sustaining a chain reaction, but uranium 238, which forms most of the remaining 139 parts, and another element, thorium (neither of which are fissile), are also potential sources of heat energy. A breeder reactor is one in which these "fertile" materials are converted into the fissile fuels plutonium or thorium at such a rate that more fuel is created than consumed; in other words, the reactor, which may also serve to generate power, has a "positive gain factor." The term "fast" in this context refers to the speed of the neutrons causing fission and will be discussed again later.

WORK OF THE ESTABLISHMENT

The first stage of the British industrial nuclear power program has been based on gas-cooled, graphite-moderated reactors of the Calder Hall type. It is expected that these will be followed by liquid-thermal reactors, and then by reactors with a positive gain factor to allow a much higher utilization of fuel. Research and development work is well in hand on these advanced reactor systems and the purpose of the Dounreay establishment is to investigate the engineering, chemical, irradiation and safety problems of the operation of these reactors on an industrial scale. There are two reactors under construction at present, both of which require considerable ancillary plant. Dounreay Works is the first independent research establishment of the Authority's Industrial Group, whose other establishments, such as those at Springfields, Windscale and Calder Hall, are primarily concerned with making products for sale.

Fast Reactor Group

From the experimental fast breeder reactor, which is concerned with the third stage, will come the operating experience necessary for commissioning an advanced machine, and experimental data on the behavior of fuel elements, cooling systems, and control techniques. To commission and maintain the reactor in operation, a fuel-element plant is required, together with chemical processing facilities to re-fabricate the fuel into new elements. Recovery of residues and the treatment and storage of active effluent are essential processes in this fuel cycle, to which must be added analytical control in the various plants. New or improved chemical processing methods will form part of the research and develop-

ment program. When the appropriate point is reached, the thermal output of the reactor will be linked to a 15 MW electrical generating plant, but the main purpose of the reactor is experimental.

Materials Testing Reactor

The improvement in heat rating of stage 1 reactors, and the development work necessary to implement stage 2, will depend to some extent on irradiation testing of new materials, components and coolant systems. The Industrial Group has sited its first materials testing reactor at Dounreay, which should be operating at full power in April 1958, and will be devoted to applied research and development for all types of reactor which are direct commitments on the Group. (Similar testing reactors at Harwell, DIDO and PLUTO, will be engaged on longer-term projects.) Work for the civil nuclear power stations, both present and future, will be included in the program. Initial exploratory tests on fast reactor materials will be carried out in the Dounreay Materials Testing Reactor before final application as complete components in the fast reactor itself. The chemical group at Dounreay will fabricate fuel elements and process these after irradiation, not only for DMTR, but also for DIDO and PLUTO, and British Commonwealth reactors of this type.

Research and development in special reactor experiments are already proceeding in the experimental criticality group on the site. The group is not concerned solely with reactors, but is also responsible for investigating problems of criticality in chemical plants, where fissile materials or their compounds are processed. Thus fluids containing fissile materials are carried in flat slab vessels which, owing to their geometrical configuration, make a chain reaction impossible no matter how concentrated the fissile constituent.

The fabrication of fuel elements using new and improved fuel materials, including plutonium, will be developed not only for the fast reactor, but also for existing and future reactors under consideration by the Industrial Group. The Dounreay Works is thus contributing to stage 3 developments of the power program by operation and experimental use of the fast reactor, and to stages 1, 2 and 3 by irradiation experiments in the testing reactor. To this must be added applied research and development on fuel elements and criticality problems, which are linked to a wide field of Authority commitments.

FAST BREEDER REACTOR

The Dounreay fast reactor, which is due to begin criticality trials in April 1958, has been designed as an experimental breeder reactor to utilize uranium enriched in uranium 235 or plutonium (the conversion product of uranium 238) as fuel in the core and the relatively plentiful uranium 238 or thorium as fertile material in a surrounding blanket. As fissile material is burned in the reactor core, more will be formed in the breeding blanket, and also in the uranium 238 in the core itself. The degree of core enrichment proposed is believed to be in the region of 40 per cent, so that some 60 per cent of uranium 238 will be available in the core for conversion to plutonium. The total fuel bred in core and blanket will exceed that consumed in the core. The distinction between a fast reactor and a thermal reactor lies in the speed of the neutrons which cause nuclear fission. (Neutrons are also created on fission and it is that fact that makes a chain reaction possible.)

The graphical sketch, Figure 1, which is much simplified and only intended to illustrate the points in question, may help to convey the distinction. It shows neutron capture and inelastic scattering cross-sections for uranium 238 and fission cross-sections for uranium 235. (Cross-section is a measure of the tendency for a reaction to occur between, say, a neutron and a uranium nucleus, and is measured in barns.)

Neutrons are emitted on fission with an average energy of 2 MeV but lose energy owing to the moderating effect of construction and other adjacent materials. At 0.4 MeV, which is the median energy for a typical fast reactor, it is seen that there is preferential capture in uranium 238, which does not undergo fission at these energies; thus if there is a substantial quantity of uranium 238 present, neutrons will be absorbed and plutonium produced, but there will be no fission neutrons to continue the chain reaction. Consequently all fast reactors use highly enriched uranium. Thus the critical mass, and hence the reactor core, is small, and the problem of heat removal severe, perhaps calling for the use of liquid-metal coolants.

At the thermal end of the graph it will be seen that there is preferential capture in uranium 235, leading to fission, so the presence of uranium 238 matters less. Thus where natural uranium or only slightly enriched fuels are used, a moderator to slow down the neutrons is necessary. There are also in-

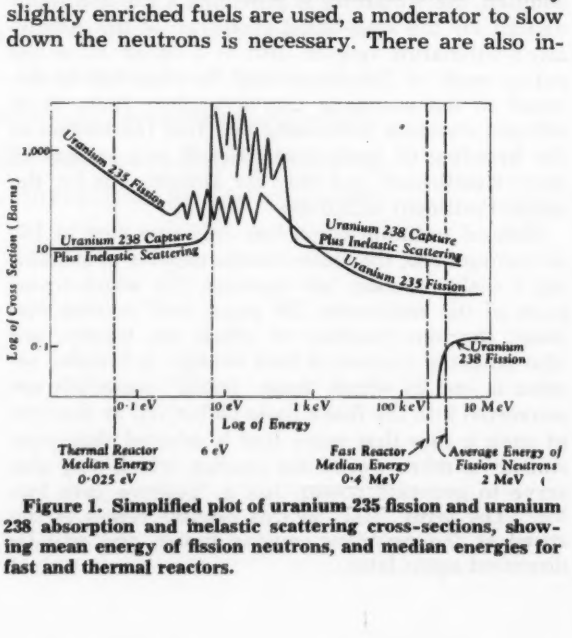


Figure 1. Simplified plot of uranium 235 fission and uranium 238 absorption and inelastic scattering cross-sections, showing mean energy of fission neutrons, and median energies for fast and thermal reactors.

termediate reactors but these will not be considered here.

The advantage of the fast reactor for breeding purposes is its neutron economy, partly because fast neutrons are less subject to parasitic absorption in structural materials: thus there are plenty of neutrons available for converting uranium 238 in the blanket to fissile plutonium, or thorium to fissile uranium 233. Conversion of this kind also takes place in a natural uranium reactor but on a much smaller scale. Certain thermal reactors (the two-region aqueous homogeneous and liquid-metal fueled systems for example) are capable of breeding but with somewhat lower gain factors. It should be noted that breeder reactors are complementary to other kinds, such as gas-cooled thermal reactors, which may use the plutonium produced; or alternatively provide a source of plutonium for use in the fast reactor core. Indeed, Sir Christopher Hinton said recently that fast reactors may prove the best way of burning the plutonium produced in thermal reactors. A disadvantage of the fast reactor at present, however, lies in the frequent fuel re-processing that is necessary. Thus, in planning a nuclear program, great consideration must be given to the overall fuel economy.

Nevertheless, the problems associated with plutonium—its tendency towards thermal distortion and difficulties of fuel-element processing—may mean that a plutonium core may not be installed in the Dounreay fast reactor until 1963, about which time plutonium from the early thermal reactors will start to become available.

Hazard

Much has been said of the hazard in operating fast reactors, but such dangers can be avoided by well considered design. The potential hazard is mainly associated with the necessarily high heat rating, and perhaps to the existence of a positive temperature coefficient (the tendency for reactivity to increase as temperature rises) in certain circumstances. Thus if the fuel melted owing to inadequate cooling, it might flow together at the base of the containing vessel to form a super-critical mass so causing an explosion, which though comparatively small would seriously damage the installation. For this reason the vessel is so designed that the fuel on melting would be divided into several different streams. The high heat rating also calls for liquid sodium cooling, a dangerous material chemically (it is highly inflammable and reacts vigorously with water, with which it is associated in the secondary heat exchangers). The eventuality of leakage is well provided for; the lines carrying the sodium are separated by a laminated matrix from those containing water, and the reactor sphere can contain any pressure likely to arise from chemical reaction.

Arrangement of Reactor

The source of power in the Dounreay fast reactor is the fission of uranium 235 and uranium 238 in the reactor core. Since the fast neutron chain reaction cannot be sustained in natural uranium the fast reactor core contains a high proportion of uranium 235, possibly 40 per cent. The reactor core, in which 60 MW of heat can be generated, is 21 in. in diameter and 21 in. high and consists of uranium rods, sheathed in niobium containers, arranged vertically in a closely packed array. Surrounding the reactor core is the breeding blanket comprising about 2,000 rods of natural uranium arranged vertically, each rod being 8 ft. long and 1¼ in. in diameter. Together core and blanket contain some 65 tons of uranium.

The reactor core and breeder are housed in a stainless-steel pot, or reactor vessel, which is 10 ft. 6 in. in diameter and 20 ft. high. Thought to be the most complicated vessel ever fabricated, it has been built by John Thompson Limited. Into the top of the reactor vessel is pumped the liquid sodium-potassium coolant which flows down over the core and breeding blanket, thus removing the heat generated by fission and transferring it to a series of concentric-tube type heat exchangers located inside the reactor vault. The sodium-potassium alloy is not the eutectic but a 70/30 alloy; eventually pure sodium may be used since it presents fewer metallurgical problems but for initial operation the low-melting point alloy will be less likely to solidify when the reactor is cold.

The vault is a concrete structure contained in the base of the reactor sphere. It supports the reactor vessel and houses all the heat exchangers and coolant pipework associated with the primary cooling of the reactor core and breeder.

Heat is transferred from the primary liquid-metal coolant to liquid metal in a secondary coolant circuit in the concentric tube heat exchangers, also fabricated by John Thompson Limited. The secondary coolant then passes out of the reactor sphere in stainless-steel pipes to the heat-exchanger house. Here the heat in the secondary liquid-metal coolant is transferred to water in a set of copper-bonded heat exchangers of novel design. The steam produced will eventually be used to drive a 15 MW turbo-alternator located in the turbine hall at the rear of the heat-exchanger house.

The link building adjacent to the heat-exchanger house contains electrical equipment and switchgear primarily for instrument supplies. The Diesel-generator house contains two groups of Diesel-generator sets, one of which supplies electrical power to all pumps and equipment in the main reactor cooling circuits. The second group serves as stand-by electrical capacity for auxiliary reactor plant in the event of a failure of the National Grid supply. On the sea coast about 100 yards from the reactor is the sea-water pump house; in it are four Diesel-driven pumps which supply sea water for cooling the condenser of the 15 MW turbine and also for cooling auxiliary plant in the heat-exchanger house. Control of the reactor is effected from a control room at the

end of the administration building. At the rear of the administration building is the element storage building in which new fuel elements are stored and irradiated elements are handled prior to transfer into the cooling pond.

Reactor Containing Sphere

The reactor sphere is 135 ft. in diameter and is constructed from sections of mild-steel plate varying in thickness between 1 in. and 1⅞ in. Generally, the thicker plates have been made from Coltuf 28 steel and the thinner plates to Lloyds P403 specification. In particularly highly stressed areas around the base of the sphere Coltuf 32 steel has been used. All the steel plate used was cold-pressed hydraulically into shape prior to being welded. The sphere has a surface area of about 1½ acres and weighs over 1,500 tons; the total length of the welded seam is over two miles. All the welds were radiographically inspected.

The sphere serves two purposes. Firstly it will localize the spread of fission products formed during reactor operation, should they be accidentally released within the sphere. Secondly, it has been designed to contain any pressure variations that might occur as a result of a liquid-metal fire. Such an occurrence should not increase the pressure inside the sphere by more than 18 lb. per sq. in. or reduce it more than 3 lb. per sq. in. The reactor sphere is, in fact, one of the largest pressure vessels ever built. Access to the sphere is through an air lock 40 ft. long and 16 ft. in diameter with airtight doors at each end; the air lock permits entry to the sphere by way of the adjacent element storage building at the level of the mid point of the sphere.

Shielding

To prevent any radiation hazard inside the reactor sphere the reactor and primary coolant circuits are contained in a concrete biological shield known as the reactor vault. This reactor vault is in the form of a bowl 90 ft. in diameter and 45 ft. high with 5 ft. thick walls. The roof slab has a central hole immediately above the reactor vessel. Further shielding is provided around the vessel to prevent the secondary liquid-metal coolant and the pipework within the reactor vault from becoming radioactive. This shielding consists of a 4 ft. layer of borated graphite in which an equatorial region of pure graphite permits fission rate measurements to be taken.

Core and Blanket

The fast reactor core is composed of fissile material, in which the majority of the fission processes occur, surrounded by a blanket of fertile material which serves to reflect neutrons back into the core as they try to escape and in which fresh fissile material is generated. The main heat generation occurs in the central portion, the core proper, which is in overall shape, a hexagonal prism 21 in. high and 21 in. across the flats, made up of several hundred fuel elements of annular cross-section. Each contains, at both ends, a length of natural uranium which acts as a blanket or breeder material. The blanket is completed by surrounding this central portion with approximately 2,000 natural uranium rods 8 ft. long and 1¼ in. in diameter.

When the reactor is operating at its designed power output, the 60 MW of heat generated is removed as already stated by the liquid-metal heat-transfer medium which also cools the blanket. This liquid metal flows down between the fuel elements and blanket elements, and down the inner tubes of the fuel elements. Each element is positioned in, and supported by, the stainless-steel bottom plate of the reactor, while adequate space for the flow of the liquid-metal coolant between the elements is maintained by the fins on each outer can.

The fuel and blanket elements are canned in niobium and stainless steel respectively to contain the fissile material and fission products and to give dimensional stability to the core and blanket lattice. Niobium has a high melting point and a good resistance to hot uranium and sodium. Stainless steel is used for canning the blanket elements, since the conditions are less severe, but it is worth noting that these "less severe" conditions are, in the case of the blanket elements nearer the reactor core, more severe than those experienced by thermal-reactor fuel elements. The neutron flux, and, therefore, the heat generated in the core, is controlled by moving groups of fuel elements into and out of the core, the former movement giving increased reactivity. The fuel elements used for this purpose are identical to those in the normal reactor charge.

The essential feature of this fast reactor is that it is an experimental tool, and for this reason has been designed so that minor and major components may be easily replaced if different component designs have to be tested. This interchangeability is, in fact, so great that the whole of the assembly within the double-walled reactor vessel can be removed and replaced.

Heat Exchange Systems

The liquid metal to be used initially for heat removal is an alloy of sodium and potassium. It becomes radioactive passing through the reactor, and it is also contaminated by fission products so that it must be contained within the concrete biological shield. Its heat is therefore transferred to liquid metal in a secondary system. This secondary liquid metal carries the heat through the biological shield and out of the sphere to the heat-exchanger house, where the heat is given up in a steam-raising plant. Any steam generated in excess of the turbine requirement spills automatically into dump condensers cooled by sea water. These can absorb the full reactor heat output if the turbine is not running. The liquid metal is circulated by electromagnetic pumps having no moving parts, the only maintenance required being upon the insulation of the windings. The windings can be removed without opening the liquid-metal system; in the primary system this is effected by remote operation through

the biological shield. The system contains no valves, nor any other part requiring mechanical maintenance.

Complete failure of the heat-removal plant would very quickly result in overheating of the reactor, and to prevent such a failure the heat removal is shared among twelve independent and identical units. A unit comprises two primary liquid-metal circuits, one secondary liquid-metal circuit, a steam raising plant and a dump condenser. Each unit has an independent electrical supply from its own Diesel alternator so that the risk of a large-scale electrical failure is remote. If, in spite of the above precautions, a widespread failure of heat-exchange plant occurred, it would not be sufficient to shut down the reactor, because some heat would be generated by fission product activity after shut-down. The thermal-syphon system of heat removal is provided which uses no electrical power but relies solely on convection effects to dissipate heat to the atmosphere. Convection causes a circulation in the primary liquid-metal system from which heat is transferred to liquid metal in the thermal-siphon system. This liquid metal is also circulated by convection and transfers its heat to the atmosphere through heat exchangers in the stack. The system also dissipates a certain amount of heat during normal running.

The heat exchangers which transfer heat from the primary coolant circuits to the secondary circuits are all of tube and annulus design. Since the liquid metal reacts violently with water, the steam-raising exchanger has been designed to prevent leaks from one side to the other. Stainless-steel tubes carrying the liquid metal and the water are bonded in a common copper matrix which allows a leak of either fluid to escape to atmosphere. Apart from the heat exchangers the twelve steam-raising plants are similar in design to conventional forced-circulation boiler systems.

Charge and Discharge Facilities

Fuel elements in the reactor must be periodically discharged, because, firstly, prolonged irradiation causes physical distortion of the elements and secondly, the fuel-element efficiency falls due to depletion of the fissile material and the build up of fission products in the element. Similar considerations apply to a lesser degree for the breeder elements. The elements are therefore removed periodically from the reactor in shielded containers and placed in the cooling pond to await chemical processing. New or refabricated elements are loaded into the reactor in their place.

Removal of elements from the reactor presents a number of problems because: (1) the elements are extremely radioactive; (2) the elements are immersed in liquid metal which becomes radioactive after irradiation in addition to being chemically active; (3) the elements continue to generate heat for a considerable time after the reactor is shut down because of residual fission-product activity; and (4) the blanket gas above the liquid metal in the reactor is highly contaminated with radioactive fission products and cannot be allowed to escape into the sphere atmosphere.

To overcome these problems a charge machine has been designed for removal and replacement of elements. This machine is lowered on to a seal door on the rotating shields above the reactor vessel, and elements are moved vertically in or out of the reactor using the charge machine. The charge machine is heavily shielded to avoid any radiation hazard to personnel. Embodied in the machine is a cooling system for removing residual heat from the elements after withdrawal from the liquid metal. At the base of the machine a gas-tight door is fitted and this is interlocked to ensure that it and the corresponding seal door on the rotating shields are closed before the charge machine can be removed from the rotating shields, thus preventing direct escape of blanket gas into the sphere. When an irradiated element has been raised into the charge machine, the machine is transported by the large rotary crane to the canning station at the side of the reactor vault.

Reprocessed elements are returned from the chemical plant to an element store in the element storage building. When required for use the elements are put in a stainless-steel can filled with inert gas and raised into the canning station in the sphere. The charge machine having discharged an irradiated element into the canning station now re-loads with a re-processed element and is transported to the rotating shields where the re-processed element is lowered into the reactor.

TABLE I—*Provisional Details of Dounreay Fast Reactor*

Thermal output	60 MW
Electrical output	15 MW (with all power passing through turbines at 25 per cent efficiency).
Fuel	Enriched uranium (approx. 40 per cent enrichment).
Canning	Niobium (finned) for core; stainless steel for blanket.
Elements	21 in. long with reflector top and bottom.
Element support	Bottom end only in stainless steel plate; elements fluted to allow passage of coolant.
Element assemblies: core	21 in. high, 21 in. across flats (hexagonal prism).
blanket	8 ft. high (approx. 2,000 elements 1¼ in. in diameter).
Total weight of uranium (core and blanket)	65 tons.
Reactor vessel	20 ft. high, 10 ft. 6 in. in diameter.
Coolant	70-30 sodium-potassium alloy. (melting point 45 deg. C.).
Primary coolant reactor outlet temperature	380-400 deg. C.
return temperature	180-200 deg. C.
Drop from primary to secondary circuit	30 deg. C.
Secondary coolant temperature drop	Less than 50 deg. C.
Coolant pumps	Flat linear induction pumps (electromagnetic).
Pressure drop across pump	20 lb. per sq. in. (circuit is maintained at excess pressure to prevent pumps from "panting" due to their thin walls; thin walls are used to minimize electrical losses).
Power consumed	120 kW in group of four pumps (2 in. primary and 2 in. secondary circuit).
Nitrogen blanket (above coolant in pressure vessel) pressure	50 lb. per sq. in.
Initial steam conditions	200 lb. per sq. in. abs. and 80 deg. C. of superheat.
Cooling water flow (two pumps)	50 million gal. per day.
Containing sphere	135 ft. diameter.

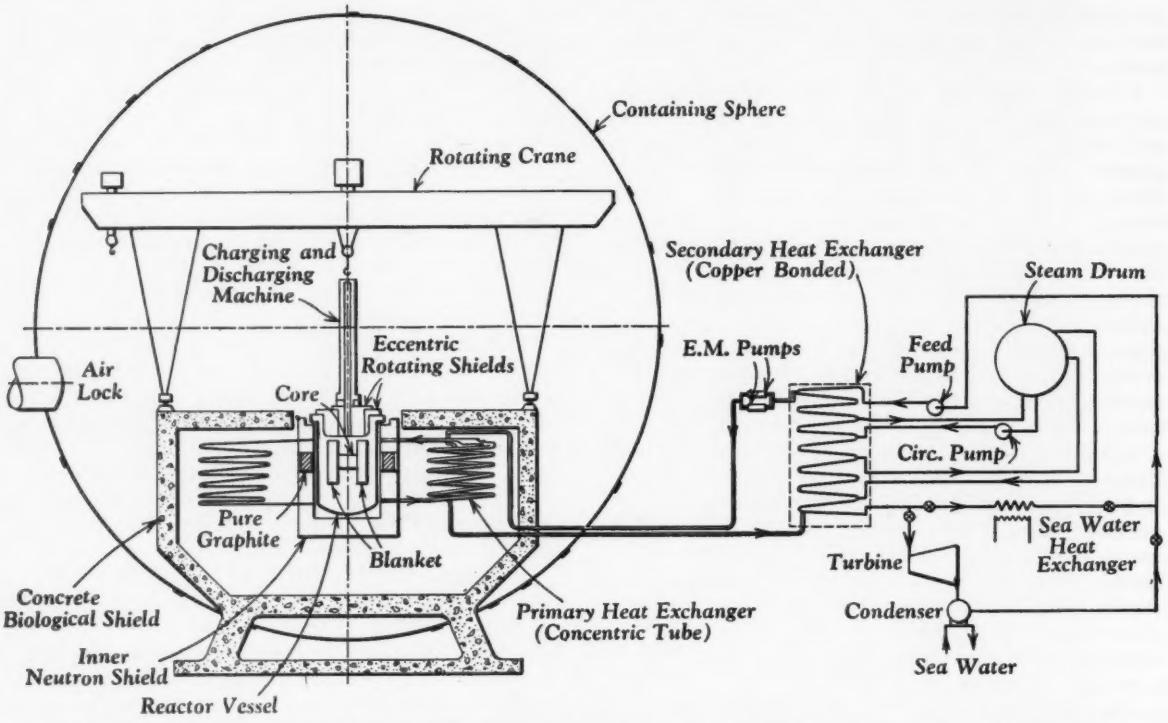


Figure 2. Layout of the Dounreay fast breeder reactor. Heat will be carried from the reactor core by a liquid metal and transferred by way of a heat exchanger to a secondary (non-radioactive) liquid-metal circuit outside the reactor vault. Steam, generated in a second heat exchanger, will pass to a turbo-generator set, giving an electrical output of approximately 15 MW.

Fig. 2, which shows the general layout of the reactor and its heat-exchange and power-producing plant, will assist in locating the various items mentioned in the following descriptions.

Reactor Vessel

The vessel for the Dounreay fast reactor is said to be the most complicated stainless-steel vessel ever produced in Britain, and probably in the world, and has taken 18 months to build. Made by John Thompson Limited, of Wolverhampton, it will contain the core of enriched fuel, the breeding blanket, the control-rod operating mechanisms, recording instruments, and the liquid-metal coolant, which surrounds the fuel and is circulated through the stainless-steel inner circuits of the primary heat exchangers.

While the core of the reactor is only some 2 ft. high by 2 ft. in diameter, the vessel containing the core and ancillary parts is 20 ft. in height by 14 ft. overall diameter and weighs 45 tons complete with top shields.

The complete vessel must be absolutely leakproof, and every welded joint has been examined by gamma or X-radiography over its complete length. Tolerances called for in fabrication of the vessel were quite outside normal practice, requiring maintenance of such limits as 0.1 per cent circularity, 0.03 per cent alignment and almost perfect concentricity where several diameters were involved. On the diameter of 14 ft., the fabrication was to within 1/32 in. Such accuracy is particularly notable since there is a diametral shrinkage of ¼ in. due to welding. Apertures for control-rod mechanisms in the vessel were machined to 3 thousandths of an inch and lining-up of the tubes carrying these mechanisms had to be within 1/32 in. in a length of 15 ft.

The complexity of the container may be judged from the following brief description. The container consists of a double-walled cylindrical outer vessel, with domed bottom and flat top, with a smaller inner cylindrical skirt reaching to about two-thirds of the depth of the outer vessel. This inner skirt, surrounded by the lower ends of the tubes for the control mechanisms and instruments, will contain the core, blanket fuel and control rods. Between the periphery of the skirt and that of the outer vessel are a series of tubes and smaller pipes running from the top of the vessel to various levels below the base of the skirt. These tubes and pipes carry the operating mechanisms and connections for the control rods and instruments which will enter the core area from the bottom of the skirt. At the tops of the pipes, instrument boxes are welded in position and pipes carry connections from these out through the wall of the vessel. Similarly, pipes from the control-rod mechanism tubes carry connections from these through the upper wall of the vessel.

The double walls of the outer vessel are of ¼ in.

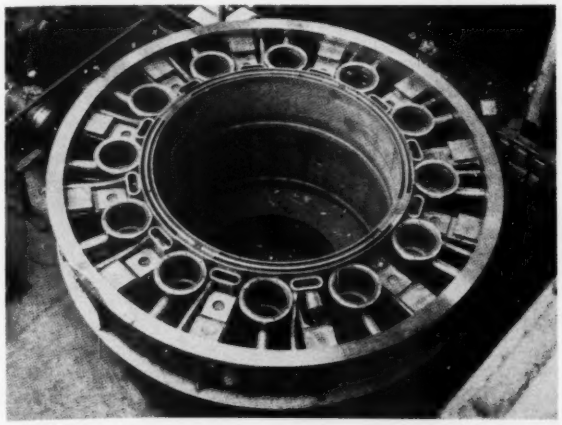


Figure 3. Part of reactor vessel. One of the rollers on which the top shields rotate is shown in the foreground. The three-walled cylinder (center) forms a liquid seal in which a double skirt fitted to the top shield rotates.

and ½ in. plate with a ⅛ in. gap between, forming a jacket around the vessel, which will be gas-filled for reasons associated with the leak-detection system. At two levels around the outer vessel there are stubs to which the ingoing and outcoming liquid-metal pipework will be welded. The inlet is at the upper level. Within the vessel the flow divides. A proportion passes through the blanket area and does not mix with the main body of the coolant, being led to four of the outlet stubs at the lower level.

The top of the vessel is a complex arrangement of rotating shields or plugs, graphite-filled and disposed eccentrically one within another so that a limited opening in the inner shield can, by movement of the rotating elements, scan the whole area of the reactor core and breeder blanket.

Rollers mounted on pads on the vessel carry the outer shield which in turn has roller pads supporting the inner shield mounted eccentrically within it. One of the rollers on which the outer shield rotates is shown in position in the foreground of Fig. 3. The three-walled cylindrical section, which can be seen at the center of the vessel, forms a liquid seal in which a double skirt on the top or inner shield rotates. During operation of the reactor the rotating shields are raised off their rollers by a jacking mechanism so that the heavy rings which form their periphery make a firm seal with machined surfaces on the member on which they are mounted. In addition, liquid seals are maintained between each rotating part during charge and discharge operations, as already explained.

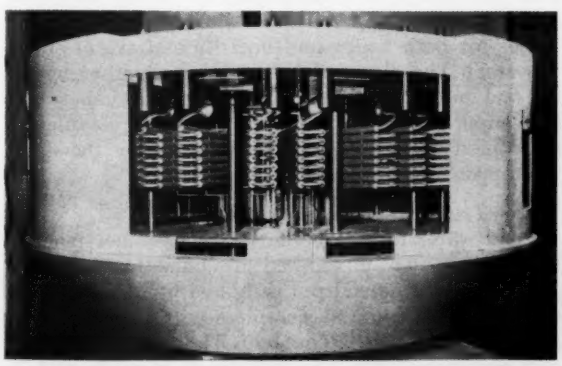


Figure 4. The arrangement of primary heat exchangers, liquid-metal pumps (horizontal cylinders) and cold traps (vertical cylinders) may be seen from this side view of the fast-reactor model.

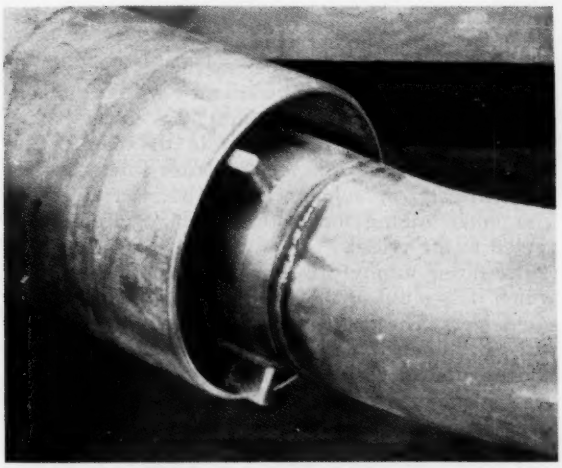


Figure 5. Stainless-steel pipework for liquid-metal heat-exchange circuits. Spiders butt-welded in place act as spacers between the inner or primary circuit connected to the reactor, and the outer circuit to the secondary heat exchangers.

Primary Circuits and Heat Exchangers

The use of liquid-metal circuits and liquid-metal to liquid-metal heat exchangers for the fast breeder reactor has necessitated special fabrication techniques in stainless steel in order to meet all the

Figure 6. Transitional section of heat-exchanger pipework. Extruded branch nipples form junctions to leak-detection circuits and secondary liquid-metal circuits.

conditions imposed; this work has also been undertaken by John Thompson Limited.

The primary or inner heat exchangers surrounding the reactor vessel and contained within the concrete biological shield, or vault, are in 24 banks. Fig. 4 shows the arrangement of the banks. The exchangers consist of inner and outer tubing spaced concentrically by spiders, as can be seen in Fig. 5. The inner tubing forms the primary circuit connected to the vessel.

The outer tubing provides the secondary circuit, which passes out of the vault to the secondary heat exchangers. The primary circuits are each provided with an independent electro-magnetic pump and cold-trap purifier and are paired to serve 12 secondary circuits. Sections of the primary circuit, not enclosed by the secondary circuit, that is, between the heat exchangers and the reactor vessel, are enclosed by tubes which form a gas-filled jacket monitored by the leak-detection apparatus. Fig. 6 shows a typical transitional piece of pipework; extruded branch nipples are for junction to leak-detection circuits and secondary liquid-metal circuits.

Since the primary circuit contains radioactive sodium during operation, and the secondary heat exchangers contain sodium and water circuits, it is essential to ensure the highest possible leak tightness. This has required the development of techniques to enable the complete system to be built as butt-welded units with argon-arc slag-free seal runs. Valves have been completely eliminated from the design. Quality control of the highest order was maintained throughout manufacture, commencing at the steelmaker's works and including intrascope inspection after hot drawing. Following cold-drawing to size, the tubes are hydraulically tested and finally inspected under water while air-filled to a pressure of 100 lb. per sq. in. Heat treatment is performed to a temperature of 1,050 deg. F (566 deg. C).

Secondary Heat-Exchange and Boiler Plant

Design and manufacture of the boiler plant by John Thompson in collaboration with the U.K.A.E.A. involved the production of a secondary heat-exchange system between liquid-metal and water that would serve as a slave to the reactor, controlling the reactor temperature. Whereas the temperature rise through the reactor depends on load and liquid-metal flow, the operating temperature level is controlled solely by conditions in the secondary heat exchange and steam plant. With this in view, the plant is designed to give utmost reliability by the use of twelve separate small boiler units, each serving one of the secondary liquid-metal circuits (and, therefore, two of the primary heat exchangers), and by the duplication of most of the auxiliary equipment by providing stand-by plant.

These boiler units will control the temperature of the reactor by rejecting heat from the system either to a sea-water dump heat-exchanger or partially to this dump exchanger and partially to a turbine.

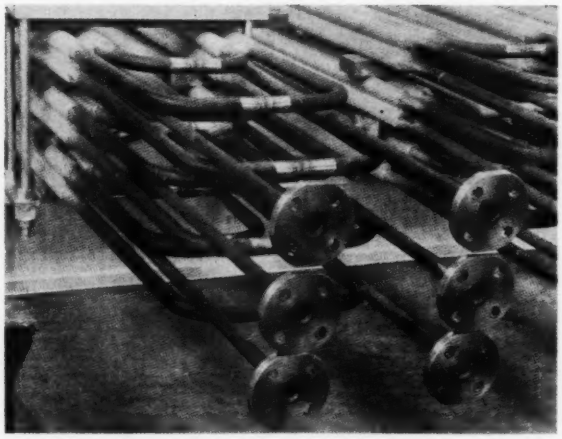


Figure 7. Close-packed copper laminations serve as a matrix for the central water tube and the four surrounding liquid-metal tubes in the secondary heat exchangers.

They are arranged to operate by rejecting heat either from water or from steam. By use of a bypass in the dump-exchange system the amount of heat dumped, and therefore the operating temperature, can be variably controlled. Superheaters and economizers are incorporated and can be isolated or brought in to suit the requirements of water dumping or steam dumping.

The 12 heat-exchanger units each comprise a steam water dump approximately 4 ft. 6 in. diameter by 4 ft. 3 in. long, with water feed boxes and steam separator, operating in conjunction with 7 banks of three heat-exchange units. Each of these 21 units is made up of 13 elements including preheaters, evaporator and superheater elements, so that in each boiler there are 21 parallel water-steam circuits. The elements each consist of one water tube surrounded by four liquid-metal tubes, the five tubes being mounted in close packed copper laminations which provide heat conductivity while also providing a means of directing any possible leakage from liquid-metal tubes away from the water tubes, and conversely. The arrangement of the five-tube sets with their copper matrix is evident from Fig. 7. Tubes for both water and liquid-metal are of stainless steel. The elements are coupled together by inlet and outlet headers for preheaters, evaporators and superheaters. The boiler units are completely instrumented, with instrument panels by the John Thompson Instrument Company.

Water Treatment and Site Work

Feed water for the boiler-heat-exchanger plant is treated by two mixed-bed de-ionization units of 1,000 gal. per hour output, supplied by John Thompson Kennicott Limited, complete with valves, piping and instrumentation. The John Thompson group are also concerned with site and erection work, and in addition have set up a special school for training argon-arc welders in the quality of work required for the liquid-metal circuits.

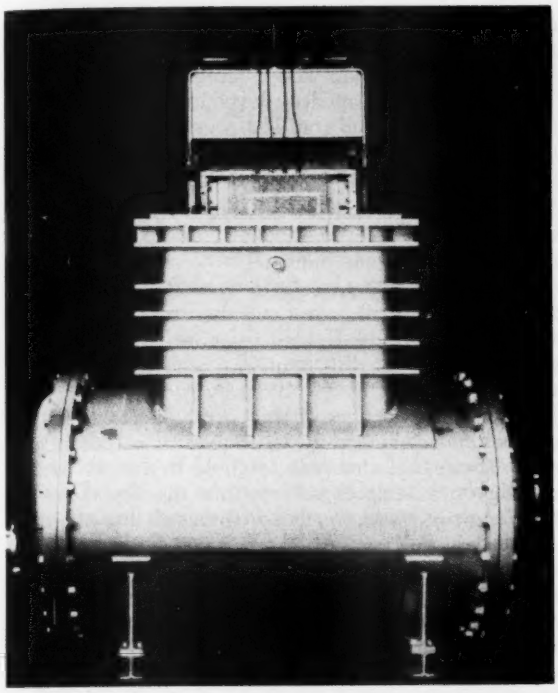


Figure 8. The stators of the flat linear induction pumps (electromagnetic) used for pumping liquid-metal coolant may be withdrawn through access columns without disturbing the hydraulic circuit. A stator is shown being replaced.

Liquid-Metal Pumps

Important items in the liquid-metal circuits are the electromagnetic pumps. Built at the Stafford works of the English Electric Company, Limited, they are of flat linear induction type and operate on the principle of the three-phase induction motor. Pumping force is applied solely by electromagnetic means and the pumps, one of which is shown in Fig. 8, have neither moving parts nor glands. Their position within the vault can be gathered from Figs. 2 and 4, where they may be seen as cylinders immediately below the upper shield.

The flat pump tube forms part of the liquid-metal circuit, and to secure a leak-tight system, is welded to the ends of the circuit. On each side of the flat tube is clamped a slotted stator carrying a three-phase electrical winding, which has class-H insulation of mica-glass-silicone. The windings produce a magnetic field in the fluid travelling along the tube, so inducing eddy currents across the liquid metal in the channel, which serve to generate the pumping force. The arrangement of a typical English Electric flat linear induction pump (F.L.I.P.) is illustrated in Fig. 9. The complete pump operates within a steel tank provided with a vertical access column. The stators can be lowered on guide rails down this column and clamped on to the pump tube by remote means; they can therefore be replaced without disturbing the hydraulic circuit. The guide rails are hinged to act in addition as pendulum links, which allow the pump to move sideways as the pipes to which it is connected expand with rising temperature. There are 24 electromagnetic pumps in the active primary circuits and a further 24 in the non-active secondary circuits. Fig. 8 shows one stator assembly (that is two stators with clamp gear) entering the access column of a secondary circuit tank. The primary circuit tanks are similar but include much longer access columns to accommodate a heavy radiation shielding plug. The tanks are filled with nitrogen and sealed.

In advance of the Dounreay project, two complete prototype pumps were designed and built by the Nelson Research Laboratories of the English Electric Company. These have been set up in a pumping rig at the Authority's Capenhurst Works and operated by the Research and Development Branch. Table II shows data for an English Electric F.L.I.P. of approximately the size and performance of those installed at Dounreay.

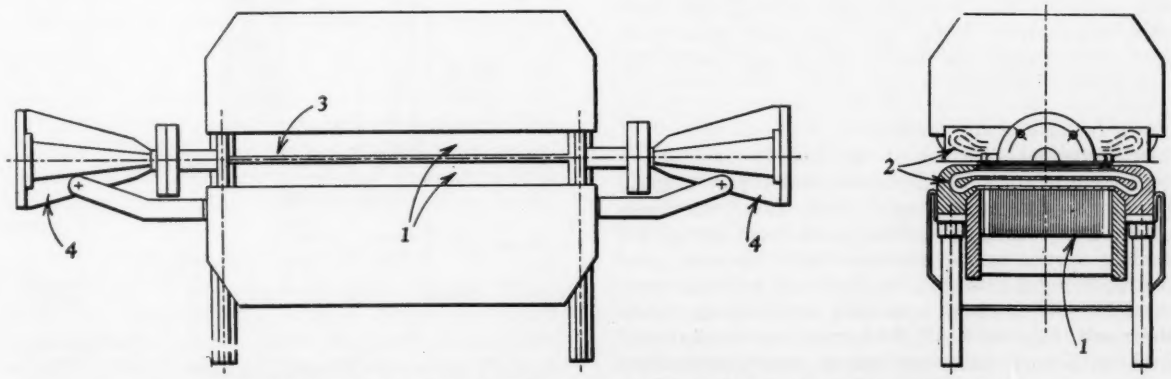


Figure 9. Layout of a typical flat linear induction pump for pumping liquid metals.

1. Cores (laminated structures of electrical sheet steel)
2. Windings (arranged to reduce the undesirable field pulsation often associated with linear devices; class H insulation permits winding temperatures up to 180 deg. C)
3. Pump tube (tube is of rectangular section; copper side bars give low-resistance paths for the current in the liquid metal and have the same function as the end rings connecting the rotor bars of a squirrel-cage induction motor)
4. Diffusers (transition between rectangular section of pump tube and circular section of external circuit)

TABLE II—*Data for English Electric Flat Linear Induction Pump of Similar Size and Performance to those in the Liquid-Metal Coolant Circuits of the Dounreay Fast Reactor.*

Pump size classification		10	(10)
Liquid pumped		70/30 sodium-potassium	(sodium)
Flow (gal. per min.)		400	(400)
(litres per sec.)		30	(30)
Pressure (lb. per sq. in.)		16	(28)
(kg. per sq. cm.)		1.1	(2.0)
Overall length including diffusers	(in.)	53.5	
	(cm.)	136	
Overall height	(in.)	20	
	(cm.)	51	
Overall width	(in.)	30	
	(cm.)	76	
Nominal bore of diffuser outlet	(in.)	4	
	(cm.)	10.2	
Weight	(lb.)	1,500	
	(kg.)	680	

Tubing

As a sub-contractor to John Thompson Limited, the Talbot Stead Tube Company, Limited, Greenlane, Walsall, supplied for Dounreay 311,000 ft. (60 miles) of stainless-steel seamless tubing in sizes ranging from ½ in. to 6½ in. outside diameter, in various thicknesses. The bulk of this tubing was supplied in straight lengths to John Thompson for inclusion in the primary heat exchangers, the bonded exchangers, and for use inside and outside the sphere. A quantity of this tubing was provided as special tube turns of 90 deg. bends and in all a total of 1,700 of these were supplied. In the liquid-metal heat exchanger, intricately machined stainless-steel spiders were needed to be used as spacers to position the inner and outer tubes, and approximately 1,200 of these were used. Over one million stainless-steel Raschig Rings were also supplied. Various other items that were delivered by Talbot Stead to John Thompson Limited included the following: control-rod connection stubs, tube connection stubs, control-rod tube corner rings, equalizing pipe stubs, indicator and heater tube end stubs, thermocouple tube end stubs, indicator tube rings, control-rod tube ends, control-rod tube branch stubs, control-rod tube locating rings, instrument-box branch stubs, thermocouple tube flanges, gas-vent connection stubs, thermocouple inner-tube stubs, liquid seal tube flanges, liquid seal tube stubs, and drain connection stubs.

Vault Insulation and Cooling

All internal surfaces of the reactor vault have been covered with metal-clad insulation panels made by Henry Hargreaves and Sons, Limited, Cook-street, Bury Lancashire. The panels form part of the cooling system on all internal vault surfaces, protecting the concrete shielding and roof columns from the effects of the high operating temperature inside the vault. Each of the 1,200 panels was constructed from mild-steel sheets and plates packed with mineral wool with over 500 perforations to accommodate the labyrinth of pipes, plant and equipment housed in the vault. The insulation was fitted, clamped and sealed in position on a system of mild-steel support channels and stools arranged so as to allow free and even air flow over all concrete and roof support column surfaces with a two-pass system serving the roof. The cooling air is introduced in a closed circuit at floor level in the vault and is forced over wall and roof surfaces before extraction at roof level for cooling and recirculation. An unusually high standard of accuracy was required, to meet which, sections of the installation were pre-assembled at the works.

Control and Instrumentation

Control of the fast reactor is achieved by movement of parts of the core, and therefore differs from the Windscale and Calder reactors, where control is effected by moving neutron-absorbing steel rods in or out of the pile. Twelve groups of fuel elements located at the corners of the core hexagon form the control rods which may be moved in or out of the core. These fuel elements are held in a metal frame resting on a support arm within the liquid metal, enabling the control rods to be raised into the core to increase its reactivity or dropped below the core to shut the reactor down. A magnetic clutch is incorporated in each control-rod drive to allow the drive to be transmitted through the reactor vessel without leakage of fission products. Each control rod and support within the reactor vessel is supported by an electromagnet, so that interruption of electrical supply to the electromagnets allows the rods

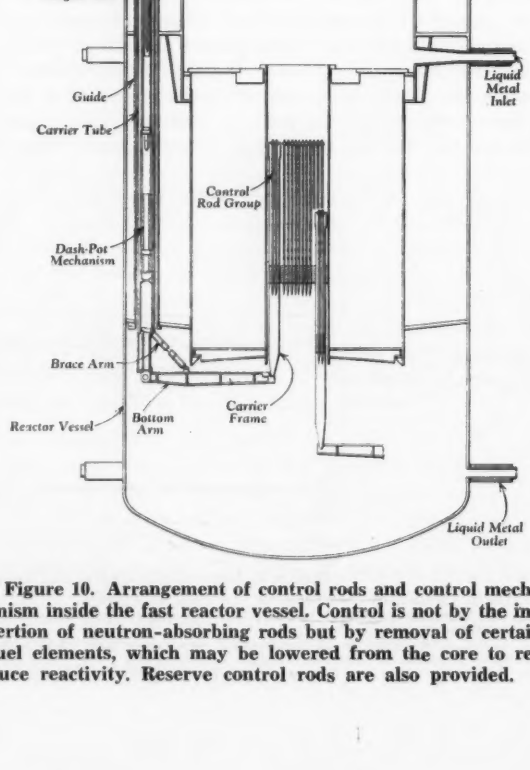


Figure 10. Arrangement of control rods and control mechanism inside the fast reactor vessel. Control is not by the insertion of neutron-absorbing rods but by removal of certain fuel elements, which may be lowered from the core to reduce reactivity. Reserve control rods are also provided.

to fall rapidly out of the core, thereby shutting down the reactor. The arrangement of the control mechanism may be seen in Fig. 10. It was made in consultation with the U.K.A.E.A. by various contractors, including Vickers-Armstrongs (Newcastle) Limited; the Fairey Aviation Company, Limited, Hayes, Middlesex; Sir W. G. Armstrong Whitworth Aircraft Limited, Coventry (control-rod carriers); and Turbine Gears Limited, Stockport, Cheshire (control-rod gear drive).

As all the twelve control rods are of identical design it is feasible that a common fault could develop in the mechanism which could prevent their satisfactory operation in an emergency. To provide a reserve control enabling the reactor to be shut down under these abnormal conditions, three rods containing neutron-absorbing boron may be dropped into the inner row of breeder elements surrounding the core. The design of these boron safety rods differs from that of the control rods, so that the possibility of their failure at the same time as that of the control rods is remote.

The positioning of the control and safety rods is controlled from a desk in the control room by means of a selector switch and push buttons. Operation of an emergency push button on the desk cuts the current to all the appropriate electromagnets and drops all the control rods and boron safety rods simultaneously. In addition to normal or emergency shutdowns controlled by the operator from the control desk, automatic shut down occurs in the following circumstances: (1) failure of pressure in the primary gas blanket; (2) high temperature in the center of the core; (3) insufficient flow of liquid-metal coolant through the core and breeding blanket; (4) a high level of neutron flux; and (5) an abnormally rapid rate of increase in neutron flux. Electromagnetic flowmeters measure the flow of liquid-metal coolant in the primary and secondary circuits, and the nuclear behavior of the reactor is recorded by means of ion chambers located in the graphite shield surrounding the reactor vessel.

All operations involving a change in reactivity are controlled from the desk in the control room. The instruments indicating or recording the behavior of the reactor and its heat-extraction circuits are grouped on the outer instrument panels. The panels on the left of the control room contain audio-signals and annunciators which give warning of fault conditions and enable individual faults to be located.

CONSTRUCTION REQUIREMENTS

The Dounreay site which occupies a former Naval airfield is generally flat with a slight northward slope towards the sea coast which is immediately adjacent. The buildings required may be divided into four principle groups, associated with (1) the fast reactor, (2) the materials testing reactor, (3) chemical processing, and (4) administrative and services. These will be discussed under separate headings.

From the viewpoint of bearing pressure there were virtually no foundation problems, since immediately below a thin layer of top soil and disintegrated rock, in total rarely more than 3 ft. thick, was encountered the top surface of a deep stratum of Caithness sandstone. One aspect which had constantly to be kept in mind was the effects of strong winds; great care had to be taken in the design of fastenings and similar items to secure the asbestos-cement cladding. In addition, to counteract the unusually severe weather conditions all external steelwork is grit blasted and zinc sprayed before erection and subsequent painting. Buildings were grouped loosely to allow for future expansion. The main civil engineering contractors were Whatlings Limited; the structural steelwork sub-contractor was Alex. Findlay and Company, Limited.

FAST REACTOR GROUP

In discussing construction work for the fast reactor group reference will be made to the reactor containing sphere and to the associated buildings which lie to east and west of the reactor. The reactor itself has already been described in detail, above.

Fast Reactor Sphere

The fabrication and erection of the 1,500 ton 135 ft. diameter fast-reactor containing sphere was carried out by the Motherwell Bridge and Engineering Company, Limited, and more than 350 steel plates were used in its construction. These plates, which are formed from Colvilles' Coltuf steel, are 24 ft. by 12 ft. by 1⅞ in. in size and weigh about 10 tons. The sphere is supported on a circular welded steel skirt with heavy ring reinforcements and requires considerable anchoring. Site fabrication was performed in a workshop at Dounreay, where plate segments were welded together in pairs to reduce on-site welding.

The sphere, set on a 10 ft. thick reinforced-concrete foundation raft, was built from the skirts upwards, with plates clipped together and tied back with booms to a center tower before welding. The bottom half was constructed between July and December, 1955, and the top half between July and December, 1956. The construction work inside the sphere was carried out between January and June, 1956. The air-lock was delivered to site in rings, assembled and welded in the site workshop, and lifted in one piece. The bellows ring was designed and made by the British Appliances Manufacturing Company, Limited, of Leeds, and the door mechanisms were designed and manufactured by Strachan and Henshaw, Limited, of Bristol. Lloyds Register of Shipping, Lands Division, acted as the Authority's inspection agents from the making of the steel to the completion of the work on site. All welders were tested and all containment welds were X-rayed. Before commissioning, the sphere will be pressure tested.

Over 300,000 ft. of "Fortrex 35" electrodes made by Murex Welding Processes, Limited, are said to

have been used for the manual arc welding of the sphere. In addition, "Nicrex" electrodes were employed for welding the 30 ton stainless-steel reactor vessel, and for other work on the site.

Fast Reactor Buildings

The buildings associated with the fast reactor number seven in all. The reactor administration building contains the control room for the fast reactor, offices, laboratories and workshops. It is a steel-framed building having three floors, asbestos-cement clad, with metal windows and steel deck roofing. The floors, with certain exceptions, are of pre-cast concrete units. The active element store is adjacent to the administration building, with which it shares an electric lift. It provides facilities for handling the reactor elements both before and after use, and incorporates a pond for storage of these elements after discharge from the reactor. A sodium stripping area is available for dealing with contaminated equipment. The building is connected to the sphere by the airlock which gives the only access to the reactor at the sphere's equator. The heat-exchanger building is also of steel-frame construction and is 62 ft. high. It contains the heat exchangers and forms the landward termination of the pipes from the sea-water pump house. The steel-framed Diesel generator building contains the generating sets which supply auxiliary power to the fast reactor. Between this building and the heat exchangers, all three forming an integrated composition, is the link building, which is partly of steel-frame and partly reinforced-concrete frame construction. It houses the switch room, battery room, workshop, offices and change rooms. The sea-water pump house, which was designed by Sir William Halcrow and Partners, and is sited on the cliff face, is of reinforced-concrete construction and houses the motors and pumps for the cooling water. The turbine hall, at present in the design stage, is a steel-framed two-story 46 ft. high building forming a northward continuation of the heat exchanger building. It will contain one turbo-alternator set.

MATERIALS TESTING REACTOR

The designers and main contractors for the Dounreay Materials Testing Reactor (DMTR) were Head Wrightson Processes, Limited, who were also responsible for supervision of construction. Fabrication and erection of the cylindrical shell, as of the fast reactor sphere, was carried out by the Motherwell Bridge and Engineering Company, Limited.

Containment Vessel

The containment vessel is a circular steel shell 70 ft. in diameter and 70 ft. high, which forms an hermetically sealed building. The shell is built on a concrete raft, 84 ft. in diameter and 7 ft. 6 in. thick. A steel-plate floor on top of the raft welded to the shell completes the seal. A steel floor is provided at the 15 ft. level and a 25 ton overhead electrically operated travelling crane is supported from the shell. Access air-locks are provided. Requirements for the design of the shell, airlocks and access doors were: to conform with B.S. 1500 for fusion welded pressure vessels; and to withstand wind velocities of up to 100 m.p.h., an internal pressure of up to 6.5 lb. per sq. in. gauge in an emergency, and external pressures up to 1.0 lb. per sq. in. gauge due to variation in atmospheric pressure. To resist the upward forces caused by the internal pressure, ten stiffening ribs are provided spaced equally round the shell. The stiffeners are extended beyond the base of the shell and cast into prepared pockets in the raft. External ribs had to be added for stiffening and for carrying the load from the crane. The junction of the roof through the radius knuckle presented some problems but the completed knuckle was pre-assembled in the shop.

Airlocks

Three airlocks are provided, one for vehicles and one for personnel at ground floor level, one for emergency exit at first floor level. The doors are so interlocked that either door can only be unclamped and opened when the other door is closed and clamped. The doors were designed and fabricated by J. Stone and Company (Charlton) Limited.

Cooling Towers

Instead of the conventional hyperbolic concrete cooling towers, "Fluor Counterflo" cooling-water plant is used for the materials testing reactor. Supplied by Head Wrighton Processes, Limited, this plant employs mechanical draft and is of low and compact construction. It makes use of a special prefabricated construction.

Fuel Element Plugs

The 130 fuel element shield plugs used in the DMTR reactor have been produced by Savage and Parsons, Limited, in conjunction with the United Kingdom Atomic Energy Authority. Each plug—approximately 4 ft. 6 in. long and 4 in. diameter—is made from a titanium-stabilized stainless-steel tube which is filled to a specified density with concrete and iron shot and a 4 in. layer of lead. Stainless-steel plugs are welded into the ends. Also housed in the main tube are three stainless-steel "purge" tubes, through which air or gases can be cleared from around the fuel element, and a center plug which can be withdrawn to facilitate the removal of water and chemicals from the core of the reactor. The fuel element and cooling sheath is attached to the bottom of the plug by a clamping ring.

Tubes

In the materials testing reactor (DMTR) at Dounreay, the Talbot Stead Tube Company, Limited, were responsible for the manufacture and fabrication of stainless-steel pipework for the following applications: heavy-water coolant, instrumentation. helium-coolant circuit, supplementary cooling, and the shield cooling circuit.

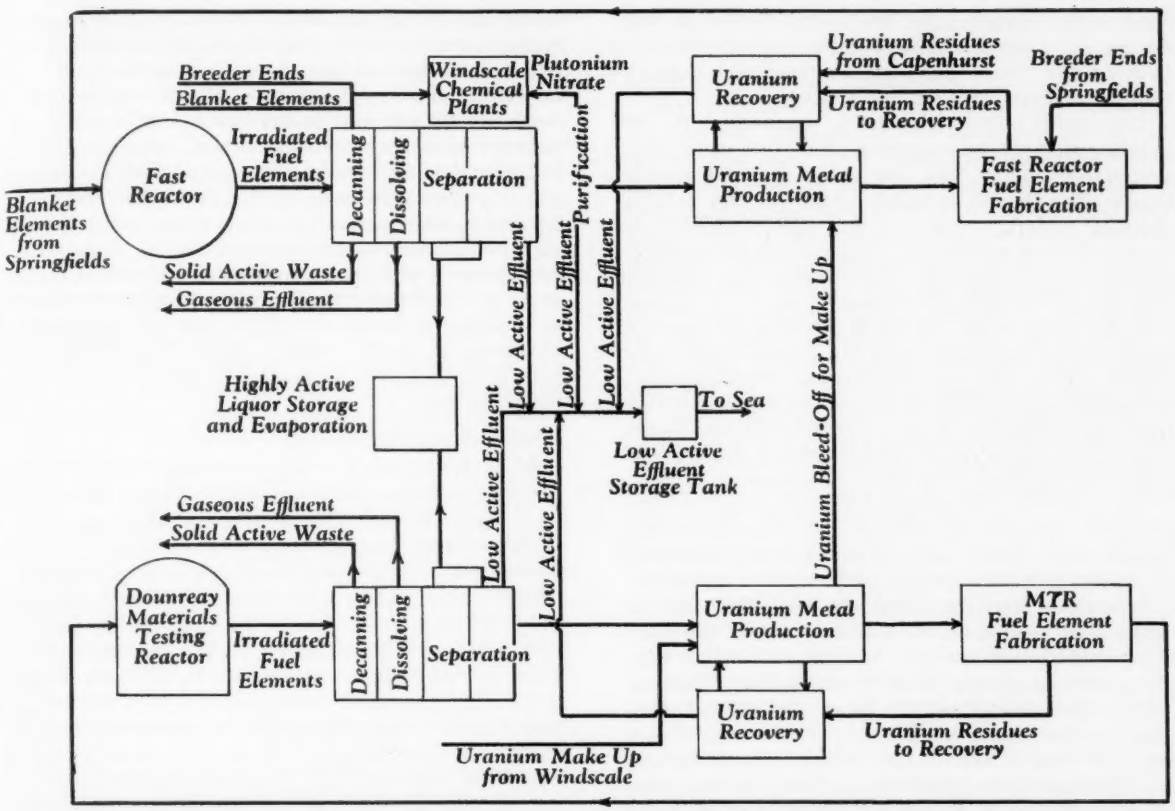


Figure 11. Enriched and natural uranium fuel processing cycles for the Dounreay reactors. In addition to the wide range of plant required for these operations, the establishment includes a number of laboratories and other experimental facilities.

CHEMICAL GROUP

The chemical group at Dounreay comprises four main sections, concerned with (1) fuel-element fabrication, (2) chemical separation and billet production, (3) effluent disposal, and (4) chemical analysis. The work of certain sections will be referred to here in describing some of the construction work involved; however, the work of the sections can be briefly summarized (see Fig. 11).

In the fuel-element fabrication section there are two distinct processes. In the first, enriched uranium metal is made into fuel elements for the fast-fission reactor; in the second, fuel elements for the material testing reactors at Dounreay and Harwell are manufactured from highly enriched uranium. In the chemical separation and billet production section, the irradiated fuel elements from the fast reactor are dissolved in nitric acid and by means of a solvent extraction process the uranium is separated from fission products and plutonium. The pure uranium in a solution of nitric acid passes to the billet plant where it is converted to metal by metallurgical processes. The billets of pure uranium metal are then returned to the fuel element fabrication plant. A similar process is used to deal with irradiated fuel elements from the materials testing reactor.

The disposal of radioactive effluent from the chemical plants is likewise the concern of a section. Highly active waste products from the chemical separation processes are stored indefinitely in underground storage tanks. Waste of very low activity is diluted and at high tide is pumped out to sea along an underground pipeline. The tidal current disperses it and it becomes highly diluted in the sea. The laboratory is the responsibility of the chemical analysis section and is the control building of the chemical group.

Effluent Disposal

The complexity of the chemical plant may be gathered from a description of the effluent disposal processes.

Highly Active Liquid Effluent

The fission processes which take place in the fast fission and Materials Testing Reactors at Dounreay produce fission products in addition to liberating energy in the form of heat. The degree of radioactivity of the long-lived fission products constitutes a hazard since the activity persists for many years. This renders the immediate discharge to sea of liquors containing these fission products impossible and the liquors are, therefore, stored in stainless-

steel tanks. Evaporation has been chosen as the easiest and most convenient method of reducing the bulk of the fission product solutions and thereby conserving expensive storage space.

The highly active effluent is discharged to the building through two separate pipe lines, one taking evaporable liquor and the other non-evaporable liquor. The non-evaporable liquor is the DMTR chemical separation plant waste liquor which contains sufficient aluminum nitrate to make evaporation inadvisable because of crystallization dangers. This non-evaporable liquor passes direct to storage and the evaporable liquor is directed to holding tanks in the building. From the holding tanks, the highly active liquor is transferred batchwise to a constant-volume feeder in the evaporation cell. This transfer is effected using a vacuum lift technique, the vacuum being produced by a steam ejector. The liquor is then fed through a steam strip column, which removes the volatile tributyl phosphate and kerosene, and then to a continuous evaporator. The concentrated fission product solution is transferred to storage and the condensate from the evaporation is monitored and discharged to sea. The plant is constructed so that all the active section of the plant is situated behind concrete biological shielding with all control equipment situated outside the shielding.

The concentrated active liquor in storage contains several important isotopes, for example, caesium 137 and strontium 90, which have industrial and medical uses. Provision is made in the plant for the withdrawal of liquor from the storage tanks and its transfer to a future extraction plant for isolating and purifying these isotopes.

Low Active Liquid Effluent

The low radioactive liquid wastes from all the chemical plants, reactors and active laboratories are discharged directly to two holding pits and thence to sea. Each building neutralizes its effluent before sending it, by way of a cast-iron pipe, to the lined pits. The pumping is done by three pumps, which are situated adjacent to the pits. Pumping is commenced one hour after high tide to ensure that the effluent is drawn away from the shore.

Gaseous Effluent

Most buildings are divided into working and plant areas. Fresh air is sucked or blown into the working area then extracted from the plant area. This arrangement ensures that personnel are always working in a fresh-air atmosphere, and should a leak develop on the plant side, the direction of flow would ensure that any contamination would be carried away in the extract system. In certain operations where active dust or gas is produced, all work is carried out in totally enclosed glove boxes. A special extract system removes the contaminated air which is then passed through special filters before going into the main extract system. The extract from each building is connected to a main duct which runs the full length of the chemical plant and terminates at the fan house and chimney. For normal operation two fans each driven by separate electric motors provide the extraction. In the event of an electrical supply failure a Diesel engine automatically cuts in and drives one fan only, thus ensuring continuity of extraction in all cases. In chemical plants which process irradiated fuel elements, gases (iodine 131, xenon or krypton) and fine particulate matter (uranium oxide or fluoride) which may be radioactive are released during decanning, dissolution in chemical reagents, and chemical treatment of solid material. The gaseous effluent system and control is designed to deal with all these types of effluent in such a manner, that the quantity and rate of discharge can cause no ill effects in the surrounding area.

Pipework and Fabrication

Thos. W. Ward, Limited, have been responsible for the installation of laboratory plant, including stainless steel, mild steel, copper and alloy pipework together with pumps, valves and fittings. Many thousand feet of stainless-steel pipework of different qualities and gauges have been installed in various parts of the site, all fabricated and welded on site and subsequently subjected to stringent examination and radiographic inspection. In addition, tanks of various sizes have been installed and numerous vessels made from stainless steel and mild steel to U.K.A.E.A. specifications. A great deal of the outside work was executed in processing and experimental cells. The flooring of the cells was completely clad with stainless-steel plate and the welding carried out to a rigorous specification. Other work carried out by Wards at Dounreay includes graphite laying, installation of control gear, pumps, process plant vessels and other items.

Ventilation

The ventilation of laboratories and ancillary buildings has been primarily the concern of Henry Hargreaves and Sons, Limited. The filtered warm air supply and active air extraction systems serving the main chemical plant buildings consist of ductwork systems constructed from galvanized and stainless steel. The main supply and extract ducts convey fresh air to "clean" areas and exhaust foul air from "dirty" areas. The air movement in the buildings is induced from a main extract plant remote from the laboratories and connected to each building by underground concrete ducts. The construction of the buildings is such that negative pressure created by extract fans induces the fresh-air supply through the duct system and filtration plant. In each of the laboratories a system of stainless-steel extract ductwork serves the cubicles and glove boxes. This part of the work is of welded construction, the joints being welded *in situ* and subjected to a test pressure of 5 lb. per sq. in. gauge.

Laboratories

There is not space here to deal fully with the work of the laboratories but reference to a few particular

items can be made. The laboratory building, which is 440 ft. long by 92 ft. wide is, apart from the reactors, perhaps the most complex single building on the site. It contains, on one floor, highly, medium and low-active laboratories with additional space for workshops, stores, plant room, mass spectrographic laboratories, dark rooms, and other premises. A particular feature is the care which was taken to provide a comprehensive system of services which are so dispersed as to allow a maximum degree of flexible planning both in the present stage and to cope with future requirements.

Irradiated Fuel Elements

Pye Limited are designing and supplying all the equipment for a laboratory in which irradiated fuel elements from the fast breeder reactor are to be examined. The equipment to be supplied includes manipulators, universal cutting machines, a lathe, furnaces, machines for X-ray and density measurement and for inspection and materials-testing, optical and television viewing facilities, and all the associated handling and shielding equipment. Owing to the highly radioactive nature of the elements, which can only be handled remotely, the laboratory is a cave of U-shaped form—a concrete cave 1,100 sq. ft. in area. For shielding purposes the walls of the cave are 4 ft. 6 in. thick, partly lined with steel. For observation of the processes inside the cave there are windows at intervals in the dense concrete walls. These windows are composed of glass-walled tanks containing a saturated zinc-bromide solution, thus providing a shield from radioactivity equal to that of the walls, and at the same time permitting observation of all the processes. At each window, facilities are provided for Pye Master Slave Manipulators for remote handling of the elements. Pye manufactured these manipulators by agreement with AMF Atomics, a division of the American Machine and Foundry Company. When close examination of the processes inside the cave is necessary, optical periscopes and closed circuit television are used.

The cave is divided into ten separate test stations for carrying out the various mechanical, physical and metallurgical operations required, all of which must of course be remotely controlled, in many cases under water. The examination and measurement of the internal and external diameters of the element calls for the use of a permanently fixed Pye industrial television camera. The de-canning of elements and removal of their rare-metal sheaths involves the use of special cutting machinery, including a remotely handled lathe for the preparation of test samples. The metallurgical tests possible include X-ray examination, density measurement, tensile and impact testing, and remote viewing of specimens under the microscope. Provision has been made for carrying out heat treatment where necessary. The highly active state of the element makes it imperative that all waste and swarf must be carefully collected and disposed of; for this purpose remote canning machines are installed and a check against loss is kept by weighing.

Mass Spectrometry Equipment

The Metropolitan-Vickers Electrical Company, Limited, has supplied an MS2 mass spectrometer for the isotopic analysis of heavy metal halides such as uranium hexafluoride. This machine is basically similar to the standard type of general-purpose mass spectrometer, which is widely in use in industry and academic research. The corrosive nature of uranium hexafluoride vapor, however, necessitates a special gas-handling system and ion source. Later this year, an MS3 mass spectrometer will be dispatched to Dounreay. This instrument is a standard machine designed for routine analytical work on gases. Early in 1958 a different type of mass spectrometer, designated type MS5, will be delivered. This instrument can be used for the rapid determination of isotope ratios of solid samples which can be handled using the surface ionization technique.

Vacuum Furnace Equipment

High-frequency vacuum induction furnaces together with their associated equipment for the purpose of casting uranium and uranium alloys have also been provided by Metropolitan-Vickers. The present installation, which is now in operation, covers nine such furnaces supplied from three 25 kW motor-generator sets together with control cubicles, capacitors, and selector switches; it is divided into two separate schemes which are electrically and mechanically separate but are so designed that a large percentage of the equipment is interchangeable reducing stocks of spares to a minimum. Each furnace is designed for melting in graphite crucibles and under high vacuum. Owing to the nature of the product all the operations are carried out in the glove boxes. The actual inductor coils are water-cooled and are protected by water-flow relays and should the water supply fall below the minimum requirements the visual and audible warning systems are brought into operation, at the same time automatically switching off the high-frequency electrical supply and thus preventing damage to the coils. Power cannot be switched on again until an adequate cooling water supply is available. This protective system is also brought into operation on vacuum failure by the inclusion of a pressure switch in the vacuum line which actuates a relay causing a magnetic valve to close in the water supply line; this ensures that a charge cannot be heated in atmospheric conditions.

POWER AND AUXILIARIES

The electrical power supply to Dounreay is obtained from the North of Scotland Hydroelectric Board at 33 kV at the main substation on the site. This forms the only source of electrical power for the chemical group, and the administrative and workshops group. The fast reactor, while using the supply as far as possible, depends on local Diesel-electric generators for all supplies because an inter-

ruption even for a short while cannot be allowed, and the materials testing reactor is equipped with Diesel generators forming a standby source of power. At the main substation, the 33 kV supply is transformed to 11 kV, and distributed over an 11 kV network of underground cables to four 11 kV substations. Two of these substations supply the chemical group, one the fast reactor and one the materials testing reactor. The main substation also supplies the administrative group workshops. At the main substation and the 11 kV substations, the supply is transformed to 415/240 volts and then distributed to the various buildings.

The main electrical contractors at Dounreay are James Scott and Company, Limited, whose work covers supplies to the chemical group, temporary installations during construction of the reactors and other items, and control and distribution.

Switchgear and Transformers

The switchgear in the main substation has been supplied by A. Reyrolle and Company, Limited, and consists of 11 kV 350 MVA oil circuit breakers of the horizontal isolation type. The busbar arrangement is duplicate busbars with a section switch in the main bar and bus couplers between each section of the main bar and the reserve busbar. Oil-immersed busbar selectors on the oil circuit breakers give facilities for on load selection of busbars. A castell key interlock ensures that the appropriate bus coupler is closed before the selector on the oil circuit breaker can be moved. The switchgear in the two 11 kV substations on the ring main is similar to that in the main substation apart from the busbar arrangement, which comprises a single busbar with section switch. Fire protection in the switchrooms is given by a carbon dioxide installation operated automatically from fusible links in the switchroom and with facilities for hand operation. The interconnector switches on the 11 kV ring main can be operated by remote control from the main substation.

The main 415 volt boards consist of 35 MVA air-break circuit breakers, also made by Reyrolle and Company, of the horizontal draw out type with current ratings up to 1,600 amperes. The busbar arrangement is single busbar with section switch and with each section of the busbar being fed by a 1,000 kVA transformer. From these boards cables run to the distribution boards in the factory buildings. These feeders are controlled by air-break switches fitted with overcurrent and earth fault relays at the supply end and by air break isolators at the remote end. The distribution boards in the factory buildings are made up of air-break switch fuse gear.

Fast Reactor Supply

The fast reactor is a power-producing plant capable of feeding 15 MV of electricity into the Grid. It must be borne in mind, however, that it is primarily a pilot plant and an instrument of research, and it is not to be expected that the reactor will produce this amount of electricity continuously, especially during the early stages. The reactor needs to be supplied with some electricity, for pumps, heaters, instruments, lighting and other items. Some of this will be taken from the Grid, and some will be generated in a power house on the fast reactor site.

The reactor is cooled by 12 independent cooling units, and the electrical equipment which serves each of these units is on a separate circuit. Twelve Diesel alternators (one to each circuit) supply the power to this equipment. In addition, there are six further alternators standing by.

The remaining electrical requirements of the reactor may be divided into three main groups, depending upon the consequences of a failure. These may be listed as follows: plant, in which a failure of the electrical supply would cause the reactor to shut down; instruments, in which a failure would mean that the operators would have no knowledge of what was happening within the reactor; and other factory services, in which a failure would have no immediate effect on the running of the reactor.

The diagram in Fig. 12 shows how power is supplied to these three groups. After transforming the Grid voltage to 415 volts it is fed into a busbar. Six Diesel alternators (each 220 kW) are standing by to feed into this busbar in the event of Grid failure. From this busbar, the current is transformed (and rectified where necessary) to suit the electrical plant. Where a break in the continuity of supply is inadmissible, that is, in the first two categories above, direct current is used and batteries are connected to the circuit to provide a reserve supply while change-over from Grid to Diesel-alternators is being effected.

Fast Reactor Generating Plant

The General Electric Company, Limited, is to supply the electrical generating plant for the fast breeder reactor. The equipment will consist of one 15 MW steam turbo-alternator set and the power generated will be fed into the North of Scotland Hydro-Electric Board Grid. The design of the turbine is generally similar to that of the standard G.E.C. single-casing machine, but it incorporates a number of special features on account of the unusual steam conditions imposed. Inlet steam will be at the comparatively low pressure of 150 lb. per sq. in. gauge and temperature of 518 deg. F. The turbine thus has to handle a very large volume of steam at inlet, and steam inlet pipes, governing and emergency valves of large capacity will be provided.

It is envisaged that the steam conditions may be improved later to 200 lb. per sq. in. gauge and 622 deg. F. The turbine has been designed to operate under these higher inlet conditions without modification. This would inevitably be accompanied by some reduction in internal efficiency, and provision has therefore been made for fitting a new nozzle block and two additional stages should a higher efficiency be desired.

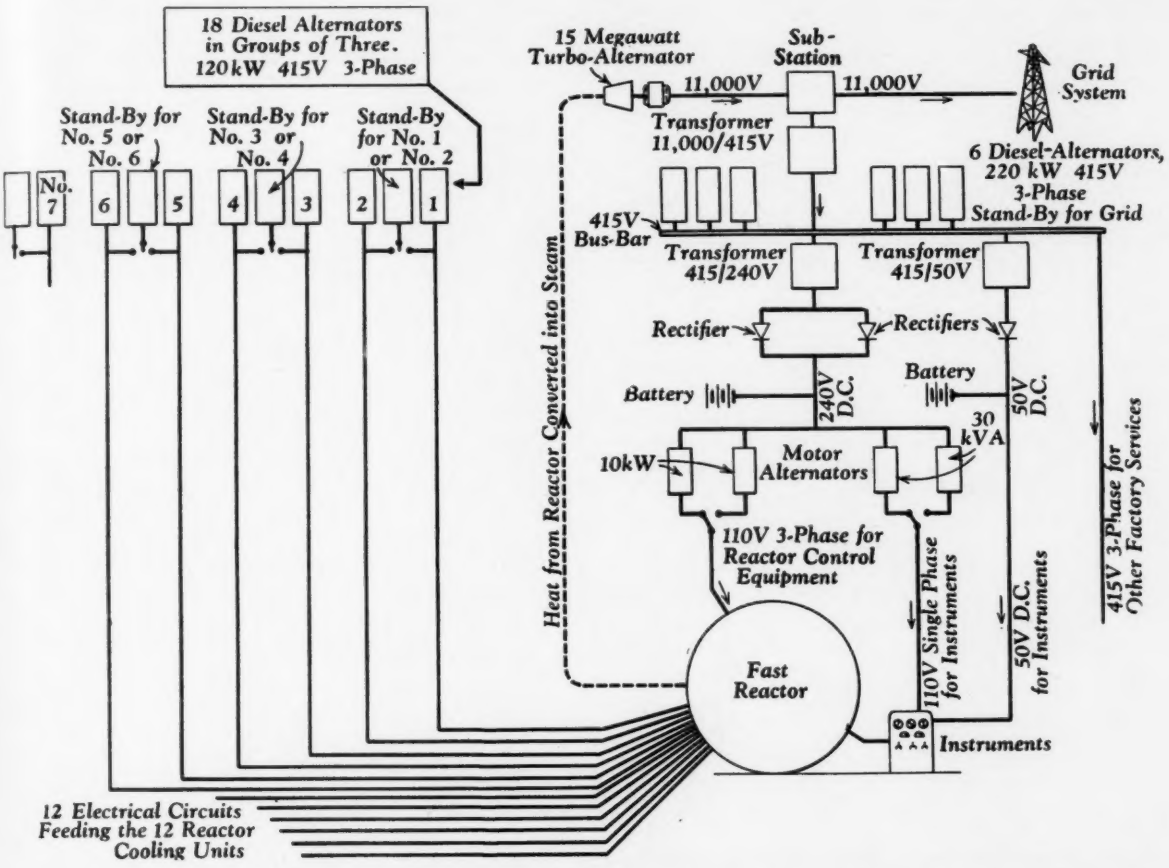


Figure 12. Electrical supply distribution for fast reactor. Auxiliary supplies are an essential feature of the system, since failure of the electromagnetic pumps might lead to melting of the reactor core.

The alternator is a standard 3 phase, 50 cycles air-cooled machine with a power factor of 0.85. The alternator will generate at 11,000 volts and has a short-circuit ratio of 0.8 to tie in with the North of Scotland Hydro-Electric Board system. The exciter will be direct-coupled to the alternator, and is being supplied with a magnetic amplifier for automatic voltage regulation.

Fast Reactor Control Gear

Brookhirst Switchgear, Limited, have made, or have orders in hand for, the control equipment for the auxiliary plant of the Dounreay fast reactor. The control equipment includes four switchboards. It incorporates eight 25/3 horse-power two-speed direct-on automatic contracter type starters for the cooling tower fans. The other three switchboards are designated "alternator control board," "distribution board" and "reactor control-rod contactor-board." These boards are directly concerned with the electrical supply to and control of the operation of the control rods, shut-off rods and safety rods. The alternator control board controls two direct-current motor-driven 10 kW alternators with 110 volt, 50 cycle, 3 phase outputs which are carefully regulated automatically for voltage and frequency, and there is provision for load sharing at a later date if required. These supplies are then paralleled by isolators in the distribution board, which incorporates a reversing contactor for each of the 12 rods. The reactor control-rod contactor board includes various arrangements of change-over contactors which control the coil circuits of the reversing contactors in the distribution board and possibly some other auxiliary circuits.

Diesel Auxiliaries

Crossley Brothers, Limited, are installing 34 two-cycle scavenge-pump Diesel engines for service at Dounreay. Twenty ESL5 type vertical two-cycle 5-cylinder scavenge-pump Diesel engines, rated at 200 b.h.p. at 600 r.p.m. will be installed in the generating house. Each set drives a 120 kW, 3 phase, 50 cycle Bruce Peebles alternator. Six ESV 8 type. V-form, two-cycle, 8 cylinder scavenge-pump Diesel engines, rated at 360 b.h.p. at 600 r.p.m. will also be provided, each set driving a 220 kW, 3 phase, 50 cycle Bruce Peebles alternator.

Three ESL5 vertical two-cycle 5 cylinder scavenge-pump Diesel engines, rated at 200 b.h.p. at 600

r.p.m. will serve as standby sets for the fast reactor, each set driving a Bruce Peebles alternator similar to those in the generator house. These sets are designed to start automatically on failure of the mains supply by a solenoid-operated automatic starting gear which introduces air into the engine cylinders.

Four ESN8 vertical two-cycle 8 cylinder scavenge-pump Diesel engines have been provided for the sea-water pump house. They are rated at 320 b.h.p. at 600 r.p.m., driving through "Twiflex" automatic clutch and flexible couplings to a David Brown gearbox, and hence into a Gwynnes centrifugal pump. One ESN3 3 cylinder vertical two-cycle scavenge-pump Diesel engine, rated at 192 b.h.p. at 960 r.p.m. will be employed as standby set for the fan ventilation system. This set is fully automatic on mains failure, and Airflex clutches incorporated in the shaft system enable drive to be obtained automatically from either end of the engine to either of the two double-shaft motors.

For lubrication of the Diesel engines, Shell Rimula Oil 30 will be used.

CRANES

In addition to the cranes used in construction, a number of permanent cranes are installed at Dounreay.

Crane for Fast Reactor

J. H. Carruthers and Company, Limited, built the 25 ton rotating crane which is housed in the fast reactor sphere. It is supported on the concrete vault and carries two hoists.

The 30 ton electric overhead travelling crane being supplied by Paterson Hughes Engineering Company, Limited, is a 4 motor crane operating on direct current supplied by a Lancashire Dynamo Nevelin rectifier mounted on the floor. The leading particulars of the crane are as follows.

Main hoist capacity	30 tons at 5 ft. per min.
Auxiliary hoist capacity	5 tons at 20 ft. per min.
Cross travel speed	45 ft. per min.
Longitudinal speed	50 ft. per min.
Span of crane bridge	57 ft. 8¼ in.

Both hoist motions are provided with potentiometer diverter control embodying dynamic braking and both travel motions also incorporate diverter control. By this means precise positioning of the hook can be obtained. Each hoist controller is fitted with a dead-man's handle and limit switches are fitted to all motions. Two entirely separate hoist motions are mounted on the crab of 30 tons and 5 tons respectively. This crane provides the main lifting facility in the building housing the reactor.

Cranes for MTR and other Plant

Among the cranes made by the Wharton Crane and Hoist Company, Limited, for the Dounreay establishment is a 25 ton 3 motor enclosed type circular-motion crane in the materials testing reactor building, details of which are as follows.

Track diameter	66 ft. 6 in.
Clear lift of hook	60 ft.
Operating speeds	
Hoist—fast	16 ft. per min.
slow	2 ft. per min.
Cross traverse	60 ft. per min.
Revolving speed	15 ft. per min (at runners)

Other Wharton cranes at Dounreay are a 20 ton 4 motor crane in the turbine house, a 10 ton single-motor crane in the Diesel engine hall, a 10 ton single-motor crane in the sea-water system load pumping bay, a 5 ton hand crane in the screen house, and two 12 ton 3 motor cranes, a 25 ton 3-motor crane, and a 25 ton 3-motor crane in various other buildings, making 9 in all.

Plans for a second type of nuclear propulsion for merchant ships have been announced by the Maritime Administration. This plant is proposed to be a gas-cooled reactor coupled with a gas turbine propulsion plant in a closed cycle. Expectations that more efficiency, lighter weight, and reduced space can be realized in the gas reactor arrangement have led to the current interest in this arrangement for ship propulsion. The design, constuction and testing of a turbine power plant for such an application is being sponsored as a joint project by the Maritime Administration and the Atomic Energy Commission.

—Press Release by Maritime Administration

CAPTAIN MARVIN H. GLUNTZ, U. S. NAVY

WEBB—A DREAM COME TRUE

THE AUTHOR

graduated from the U. S. Naval Academy in the Class of 1930; took graduate work in naval construction at the Massachusetts Institute of Technology and then had duty in the Boston, New York and Bremerton Naval Shipyards. Served on carrier and battleship staffs and was Head of the Industrial Department, Naval Operating Base, Guam, at the end of World War II. For the past three years he has served as Industrial Manager, Supervisor of Shipbuilding and Naval Inspector of Ordnance in the NINTH Naval District, Chicago. He is presently attached to the Bureau of Ships.

IN 1870, Mr. William Webb reached a tough decision—to retire from the shipbuilding business in favor of his burgeoning ship operation interests. He was then only fifty-four years old and had already built more ships in number and total tonnage than any other man in America. Some of his ships were record-setting clippers. His *Comet*, still holds the record for the San Francisco-to-New York run around the Horn. Other ships possessed features considered advanced for the times.

These successes made him quite famous and widely sought after. Our Navy commissioned him to build the *Dunderburg*, largest and fastest naval vessel of the period. The Navy cancelled the order when the Civil War ended, but Webb bought back the ship from the Government and sold it to Napoleon III of France at a handsome profit. Italy and Russia also engaged his services in connection with their armored warship construction programs.

Those accomplishments were also rewarded with substantial financial success. But in spite of all that, he was dissatisfied. Shipbuilding, he felt, was too much of an art and too little of a science. His speed-winning hulls resulted from luck and hull forms which he had whittled from hunks of wood rather than from mathematical calculations and scientific curves of form. Still, there was no school in the country that taught naval architecture. You learned to build ships on the job, and you first worked as an apprentice in one of the shipyards.

Dissatisfaction became an obsession and from that, a dream began to take shape—a dream of a college which would give a top-notch technical training in naval construction and marine engineering—free of charge.

The dream came true while he was still alive; because in 1889, ten years before his death, the State of New York granted a charter to Webb's Academy and Home for Shipbuilders. But it was 1894 before the school, built on some farm lands in the Bronx opened its doors to any students. Eventually, it gave up being also a home for retired shipbuilders and became simply Webb Institute of Naval Architecture.

The years passed, and the school became surrounded and hemmed in by apartment houses. In 1946, Mr. J. Lewis Luckenbach, Webb Trustee, was able to negotiate a favorable real estate transaction by disposing of the Bronx property and purchasing the twenty-six acre Pratt estate at Glen Cove, Long Island, New York, with no loss of investment funds. The school moved to its new location in April, 1947.

As a result of Luckenbach's favorable real estate transaction, the Webb student today lives in the midst of an estate-studded countryside which, with its landscaped and seascaped scenery, is a bit breathtaking to the visitor who sees it for the first time.

He is invariably impressed too with the small size of Webb's student body—a total of around sixty-five. If he inquires, he is told that the top number the school can accommodate with its available facilities is about seventy. So, the school must restrict its freshman input to around twenty. Attrition, mainly resulting from academic deficiencies, usually keeps the total student body a few below the upper limit.

Webb would like to see a bigger percentage make

One of the formal classrooms.

the grade. Each one of their men is hand-picked before he gets in. They are leaders both in academics and extra curricular activities in their high schools, and they are in the top twenty of those selected by Webb to take the competitive exams. But Webb will not compromise its tough scholastic standards.

Contrasted with the heavy investment the student makes in academic effort is the almost negligible one he makes in dollars. His tuition, board, room, textbooks, and even laundry are free. Indeed, his only out-of-pocket costs are for clothes, vacation expenses and personal incidentals. And most students fund these out-of-pocket costs from wages they earn each year during their winter work period.

There is little doubt that Webb's low price tag exerts an appeal on parents who have watched their pay scales lag so far behind the rise in the cost of living. But even the thousands of dollars that Webb can save them wouldn't mean too much if quality were absent.

Just what is Webb's quality then? We will consider this question more fully later on, but for a partial answer let's see what the Navy Department thinks. From around the turn of the century, our naval officers and later, our engineering duty officers had gotten most of their formal postgraduate training from M.I.T. In 1949, Rear Admiral David L. Clark, then Chief of the Bureau of Ships had a Board of Officers look into the desirability of having a second source of postgraduate education in naval construction and marine engineering. In the course of the Board's study, three of its members visited Webb. Those officers were: Captain (now Rear Admiral) S. N. Pyne, the author, and Lieutenant Commander J. H. Redding. They talked with students, faculty, the Administrator, Admiral S. M. Robinson, USN (Ret.), and with Webb's President of the Board of Trustees, J. Lewis Luckenbach. They inspected class rooms, shops, labs, student living quarters, athletic facilities, grounds and even the local countryside for availability of housing. These officers gave their findings to the Board which in turn recommended sending four Prospective Engineering Duty PG students to Webb annually. The Chief of Naval Personnel acted favorably upon the Chief of the Bureau of Ships recommendation, and in 1950, the first group of student naval officers entered Webb.

The Navy's decision was in no way a reflection on M.I.T.'s performance. The Navy still sends the big majority of its prospective engineering duty officers to the school on the Charles; but its objective of developing a second source for post graduate work in ship construction has been realized.

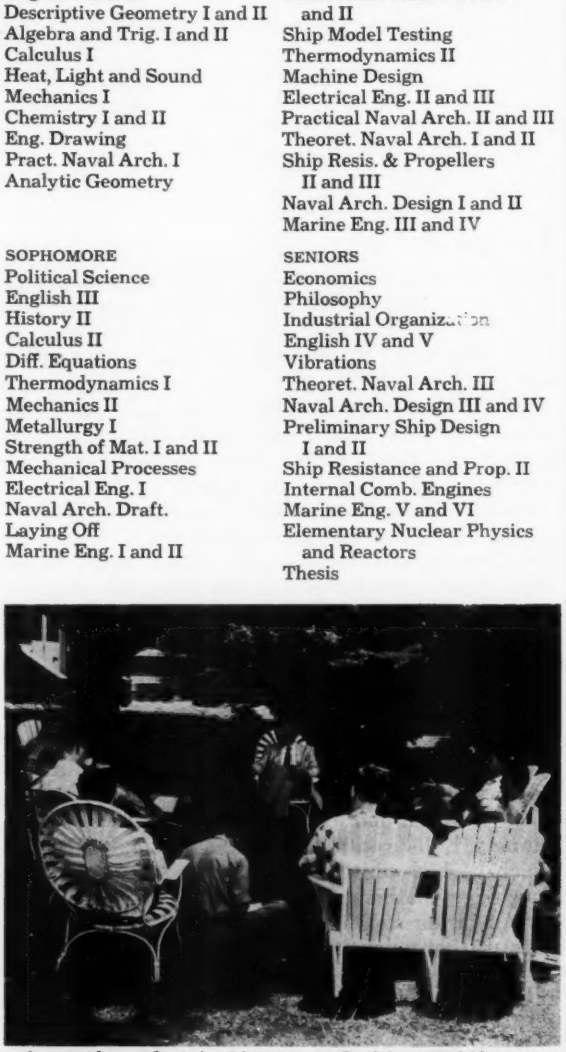
What accounts for Webb's quality? It all boils down to three key factors: curriculum, faculty, and student selection. The latest curriculum is printed

FRESHMAN
History I
English I and II
Descriptive Geometry I and II
Algebra and Trig. I and II
Calculus I
Heat, Light and Sound
Mechanics I
Chemistry I and II
Eng. Drawing
Pract. Naval Arch. I
Analytic Geometry

SOPHOMORE
Political Science
English III
History II
Calculus II
Diff. Equations
Thermodynamics I
Mechanics II
Metallurgy I
Strength of Mat. I and II
Mechanical Processes
Electrical Eng. I
Naval Arch. Draft.
Laying Off
Marine Eng. I and II

JUNIOR
Mechanics III
Theoretical Fluid Mech. I and II
Ship Model Testing
Thermodynamics II
Machine Design
Electrical Eng. II and III
Practical Naval Arch. II and III
Theoret. Naval Arch. I and II
Ship Resis. & Propellers II and III
Naval Arch. Design I and II
Marine Eng. III and IV

SENIORS
Economics
Philosophy
Industrial Organization
English IV and V
Vibrations
Theoret. Naval Arch. III
Naval Arch. Design III and IV
Preliminary Ship Design I and II
Ship Resistance and Prop. II
Internal Comb. Engines
Marine Eng. V and VI
Elementary Nuclear Physics and Reactors
Thesis



An outdoor class in history emphasizing Webb's tutor-like atmosphere.

Holding an informal class—again emphasizing Webb's tutor-like atmosphere.

herein in order that the reader may see for himself the scope of subjects covered, and may also compare it with those required by other schools. It also indicates why a Webb graduate can engage in several different types of engineering work if he should not elect to follow naval architecture.

There is an impressive total of 173 credit hours in the above subjects—about 25% more than that required by other engineering colleges. And although Webb is not unique in giving its seniors a taste of nuclear physics and reactors, inclusion of this course in an already heavy schedule serves to widen the scope of Webb's engineering subjects, and to highlight the school's up-to-dateness.

The second key factor accounting for Webb's quality is its faculty. Each teacher is a leader in his field. Some are themselves Webb graduates. Their above-average pay attracts and holds the best. And with each class averaging between ten and twenty students, there is naturally a very personal relationship between professor and student—a tutor-like feature that breeds academic achievements.

The third consideration is, of course, the student himself. What is he like? What must he do to meet Webb's exacting rquirements? Suppose we meet him and see for ourselves.

During high school he averaged above 85 in math and physics, and his grades in the non-technical subjects like history and English were "good" to "excellent." In short, he was more of an "A" than "B" student in high school and stood in the upper ten per cent of his class. He also possessed skill in a number of interests other than scholastics.

He learned of Webb's existence and a little about the school while in his junior year at high school. He had filed his application during his senior year and before the February 15 deadline date. Along with it, he sent a copy of his birth certificate, a transcript of his high school record, a statement from a physician, and had asked at least two persons (one from his high school faculty) to send in a confidential letter to Webb about himself.

Rich wood paneling is found throughout Stevenson Taylor Hall and is conducive to study and reflection.

By that time, his heart had been set on going to Webb, but to play safe, he took at least two different sets of college boards administered by the Educational Testing Service so that if he were not selected for Webb, he would have satisfied the academic requirements for admittance to his school of second choice. So there was a flurry around the house when the telegram arrived telling him and his parents that he was one of twenty boys selected.

Once at Webb, he adopted a study pattern that permitted him to meet the exacting scholastic requirements as well as to take part in one or more of Webb's inter-collegiate athletic programs; basketball, tennis and sailing.

It was tough to win meets from other colleges with a student body, including freshmen, totaling around sixty. But he tried and he had some success. In 1954, for example, his dinghies crossed the finish markers

Learning machine technique at the Brooklyn Naval Shipyard during the student's first winter work period.

Time out from the books on Webb's private beach.

on Chesapeake Bay ahead of them all—including salty Annapolis.

A Webb football team was just not in the cards, but every class played each other twice each fall in touch football. Inter-class softball games were fun too. These games did much to make each student become acquainted with every other student. That's something! In most col'eges, you don't even get to know all of your own classmates, let alone students in the other classes!

He also seized every opportunity to expand his cultural horizons. During his freshman work period, right after New Year's, he and his classmates learned not only to weld and operate machine tools at the New York Naval Shipyard, but they also caught up with the latest Broadway hits. They attended the Symphony and Ballet, and the best athletic events at the Gardens. Student Trainee's wages paid by the shipyard enabled him to take on that cultural program without too much financial strain.

During his second work period, exactly a year later, he and his classmates, as Engine Cadets, were nursing boilers, pumps, and turbines in the machinery plants of several merchantmen on cruises to the Mediterranean, the Baltic, Africa, or South America.

The Luckenbach Graduate School.

Wages were modest but room and board were taken care of so it wasn't too tough to take advantage of the opportunities these cruises afforded.

Junior and senior work periods gave him an indication of life after graduation. By then, he had acquired a fair technical background and industry paid him well because he could gross up to $1,300 during these periods.

The reader may wonder how Webb accommodates the winter work period without shortcutting its academic terms. The latter, sixteen weeks long, is the same as that found in most colleges. Webb's solution is to shorten the summer vacation to about seven

Learning to weld during the freshman work period.

weeks. That's really not too bad because the winter work period provides a good change of pace.

If the student really wants to, he can give himself a week's spring vacation by cutting his work period short a bit. But, since he gets a grade for this period based upon a report he and his employer submit to the Administrator and faculty of the school, the student is going to think twice before he cuts that work

Informal design conference—repeated many times on each student project.

Main Building—Stevenson Taylor Hall.

Main Building—Stevenson Taylor Hall.

period. What actually happens is that most students work right into the last week and allow themselves just enough time to get back to school. They don't feel the need of a spring vacation, and besides, they want to collect as many pay checks as they can.

A visitor may ask, "Is there any social life during the academic terms, or must a student lock himself up in his textbook world?" The answer is, of course, that Webb has its lighter side with alumni smokers, plays and sports events—and just plain bull sessions. Three or four dances each term highlight the social calendar.

The outstanding influence on the student at Webb though is the honor system which is administered by the students themselves. It is concerned not only with academic integrity, but with all student activities. It is a way of life. It is dedicated to the development of leaders and gentlemen of the highest caliber. It succeeds at Webb.

When the student returns from his senior year work period, he becomes pre-occupied with his thesis and post-graduate commitments. If his thesis includes the need for model basin data, he's most fortunate to be able to use Webb's own 93-foot model basin—the only one in the country reserved for the sole use of its students.

Webb's graduates proceed in three broad directions: to postgraduate courses, to the Navy's Officer Candidate School, and to jobs with industry. Those choosing post-graduate work are most likely to take either an engineering course or business administration course. Those receiving commissions after Officer Candidate School are usually assigned to some field activity of the Bureau of Ships—a Naval Shipyard or a Supervisor of Shipbuilding Office. They could get no more valuable training. The graduates who take jobs with industry have many choices. A majority of them go with shipbuilding firms or design agents. Some start their own businesses, some teach, and a sizeable number accept positions with firms in various industries—petroleum, electrical, construction and several others.

And what do these industries think of the Webb graduate? By early April, 1957, one company had already offered a cool $625 per month and $500 offers were a commonplace.

One of the important reasons why Webb has maintained the highest engineering standards is the quality and dedication of its administrators. The present Administrator, Rear Admiral Frederick E. Haeberle, USN (Ret.) is a good example. Early in his naval

Preparation for an afternoon of sailing.

Preparation for an afternoon of sailing.

career, he was chosen to take his post-graduate course in Naval construction and marine engineering at the Massachusetts Institute of Technology. After graduation, with a Master of Science degree, he spent some thirty years in various positions of increasing responsibility in the design, construction, and repair of all types of naval vessels. Most of the working plans for our Navy's largest and newest World War II aircraft carriers and battleships were developed under his supervision, and throughout his naval career he worked with Navy's high standards of quality. He has carried those standards into his position as Webb's Administrator—a position he has held with distinction for the past six years. During this time, several important changes in curriculum have been effected—a modern well-equipped Marine and Electrical Engineering Lab has been erected, and Webb prestige in general has been boosted to a new and higher plateau.

Admiral Haeberle's predecessors: Admiral S. M. Robinson, USN (Ret.) and Rear Admiral George H. Rock, USN (Ret.) all left their mark on Webb. Admiral Robinson helped set up the Navy PG program at Webb. It was he who persuaded Webb's Trustees to authorize the construction of a special building to accommodate the Navy students and to house certain special features such as vaults to protect classified material. Other Robinson accomplishments included raising enough funds to build the school's model basin and installing the honor system and honor code as it is known today.

Rear Admiral Rock was responsible for getting Webb accredited by the Educational Council for Professional Development, one of the most exacting accreditations to meet. And, during World War II he opened Webb's doors to the V-12 program.

It would not be feasible to name all of those graduates who have achieved notable success. In Government, John Niedermair is best known for his work as Technical Director of the Navy's Bureau of Ships Preliminary Design Branch, the branch that dreams up the warships of tomorrow like the *Nautilus, Forrestal,* etc. He has had such a personal part in hundreds of these designs that he has been called the Father of Today's Modern Navy, and last year, the National Service League chose him to receive one of ten Career Service Awards it bestows annually.

Edward L. Teale, Webb '34—a comparatively young man as top management goes—is President of New York Shipbuilding Corporation.

Frank M. Lewis, Webb '17, attached to M.I.T.'s faculty, is considered by many as this country's top authority on torsional vibrations.

Yes, Mr. Webb's dream came true. His funds gave it the start. The faculty, administrator, students, trustees, and grants from private parties have kept it alive and vital. We believe Mr. Webb would be pleased and amazed with the job they have done. We also believe he would advise going all out for dreams provided they were big dreams—the kind that help people and the nation. His dream was that way.

Plotting strategy for the next race.

CAN SCIENTISTS BE PROPHETS?

ACKNOWLEDGEMENT

Dr. C. Guy Suits, Vice President and Director of Research, General Electric Company, is the author of this article. It appeared in the May 1957 "General Electric Review."

NEW YEAR'S Eve, December 31, 1999, should be a big occasion. Almost all of you who missed the last turn of the century have thought—privately, at least—about your chances of being on hand to start writing a letter by putting "January 1, 2000" at the top of the page. Probably you have already computed how old you will be.

Although some of you might have to be a bit optimistic about longevity, you probably still find yourselves guessing what the world will be like when you prepare for that special New Year's Eve. Will you watch—on wall-size three-dimensional color television—crowds cavorting across Times Square enjoying the balmy winter weather specially adjusted for the occasion? Will the program include remote pickups from places where years don't have 365 days? And what will you actually think about the 20th century as you sing *Auld Lang Syne* to a whole 100 years?

UNIVERSAL GUESSING GAME

Less than a century ago, Jules Verne had a virtual monopoly on this business of guessing what science might do in the future. Today he would find the competition tougher. Everybody seems to be a prophet, amateur or professional, and this crystal ball gazing isn't limited to children's television shows or the more fantastic pulp magazines. Some of the most respected and dignified journals have also succumbed. Wherever you look these days, there's an article, or an artist's conception, or a fanciful TV stage setting telling us what life will be like tomorrow.

Certainly there's nothing wrong with "looking ahead" and although an easy cliche, looking ahead represents one of the most important activities in modern civilization. For example, unless American industry looks ahead today, there may not be anything to see tomorrow. But, as with almost everything, this passion for prophecy can be overdone. The danger: Constant repetition sometimes makes prophecy *seem* to become fact.

To the man on the street, the practicing scientist may appear to be behind the times; and when he does something new and significant, surprise stems not from what he has done but from the length of time it took him. "I read about somebody doing that 10 years ago," is a comment the scientist hears more and more. Actually the *somebody* was probably the figment of a science-fiction writer's fertile imagination. *Today's fact may seem less dramatic than yesterday's fiction.*

WHAT'S IT GOOD FOR?

Recently a group of General Electric Research Laboratory scientists discovered an entirely new physical phenomenon: amplification of light within a simple phosphor film. As a brand-new phenomenon, it holds many future promises—some difficult to predict precisely. However, you can't announce something new in science without expecting to be asked that excellent question, "What's it good for?"

To some extent, predicting what the solid-state light amplifier will "be good for" isn't any easier than it would have been for, say, Lee deForest to foresee in 1906 the ramifications of the electronics industry made possible by his vacuum-tube amplifier.

Actually, seven years after inventing the Audion tube, deForest was taken into Federal Court on a charge of using the mails to defraud because "This strange device like an incandescent lamp . . . has proved to be worthless." In summing up the case, the prosecutor stated, "deForest has said in many newspapers and over his signature that it would be possible to transmit the human voice across the Atlantic before many years. Based on such absurd and deliberately misleading statements of deForest, the misguided public, Your Honor, has been persuaded to purchase stock in his company."

In announcing the new light-amplifying phenomenon, accusations of fraud were not the problems; because of the widespread science-fiction fad, we had the opposite kind of trouble. Some people

thought the announcement meant more than it did; the simple facts of a significant scientific achievement were not enough for everybody. Some insisted on reading into it the development of a device the science-soothsayers had looked forward to for so long that their readers feel certain it is long overdue—the "picture-on-the-wall" television set. This is thought of as a thin screen hanging on the wall like a picture frame and a small box full of transistors, with the appropriate control knobs, resting on a nearby table.

Picture-on-the-wall television will surely be with us someday, and the new phenomenon of light amplification in a thin phosphor film may be an important clue to its development. To help answer the what's-it-good-for question, we said as much in our announcement. But because a thin, flat screen was used as a model to demonstrate the light amplifier and because all scientists worth their salt are presumed to be looking for the flat television screen, a surprising number of people thought we had something we didn't have—despite our efforts to explain in precise terms exactly what had been accomplished.

However, many do manage to keep the present in perspective amidst the profusion of prophets. Some of this group believe that when crystal gazing is to be done, the scientist should be the one to do it. And scientists have achieved a certain reputation for clairvoyance, but actually their best soothsaying results from the distressing fact that the transition time between basic discoveries in the laboratory and everyday use often takes 5 or 10 years. In other words, they aren't guessing about the unknown, they're prophesying that the known will be put to use.

THE SCIENTIST'S LIMITATIONS

Of course, it's a speculative matter for scientists to claim that they know a particular new fact will be found or that a particular new invention will be made based on knowledge not yet discovered. However, you can ask the scientist what new things may be available *to the public* in 5—or even 10—years from now and expect a reasonably firm answer. The science that will provide these new things already exists in the laboratory. If you extend the period to 10 or 20 years, you can expect a reasonably good *educated guess*. The science that will provide these things is at least in the planning stage. For guesses beyond this, you had better turn to a crystal ball.

The scientist doesn't make a particularly good long-range soothsayer: partly because of his familiarity with certain physical limitations—the speed of light, for example; or the need for a positive magnetic pole where there is a negative one; or the basic restrictions that reside in considerations of energy such as its quantity, availability, and convertabilty. Although still cautious about it, the scientist probably will say that "some things can be done"—even the fantasies of the writer of a futuristic television program. At the same time, because he can visualize the laboratory activity required to attain a particular scientific goal, he may be appalled at the cost of converting papier-mache into solid reality.

THE DECADE AHEAD

If the scientist can look confidently at the next 10 years or so, what does he see?

The things that are just ahead range from the indispenable gadgetry of modern living to the fundamental energy generation and conversion processes of modern industry. For one thing, in the next decade we will be completely saturated with electronics. And although it seems remarkable, the electron—discovered back in 1897—is still a lusty child, far from maturity.

Tomorrow's electronics not only will be in the office, the factory, and the farm but also will perform dozens of functions in the home, including cooking. In this next decade, factories will undergo important progress in automatic manufacturing, with electronic technology as the vital key to automation. By the end of this period, automation will have become an absolute necessity, because there won't be enough people to manufacture by present methods all the things we will need. This is arithmetic, not clairvoyance. A simple industrial forecast will show that we must produce at least 50 percent more goods and services in 1966, and we will only have about 10 percent more human effort with which to do it. The inevitable conclusion: Automation.

Semiconductors represent the rich relatives in the electronics family—rich in promise and potential. Semiconductors in the form of transistors and similar devices with electronic capabilities will be found everywhere during the next 10 years. In 1966, you'll wonder how we ever got along without them.

From the long list of things that will certainly come into being during the next decade as the result of scientific research, let's consider some of them. Chemicals are manufactured today principally by the controlled application of heat, pressure, and catalysts; production by means of these processes forms the basis of the vast chemical industry. We now have a new means of promoting chemical reactions—radiation—that will become increasingly important during the next decade. Light is radiation. We have known for years about chemical reactions that could be promoted with light; but atomic radiation, especially electron radiation in the form of electron beams, presents a new chemical action. The Research Laboratory has been working with *electron chemistry* for more than 30 years, and a few materials produced by electron irradiation—irradiated polyethylene is an outstanding example—have recently come to market. But in the next decade when electron chemistry comes of age, it will make possible a host of new materials and products that can be produced in no other way.

The most publicized use of electron chemistry has been the sterilization of food by irradiation, without heat. Many optimistic reports state this technique

will eliminate refrigeration in the future. Progress has thus far been very slow. But a recent report by the U. S. Army Quartermaster Corps states that more than 40 different foods, including several kinds of meat, when sterilized by this process were found *after cooking* to be acceptable by Army standards. Much remains to be learned before the process achieves widespread civilian acceptance. Looking two or three decades ahead, you may see the general use of radiation for food sterilization become possible, but no one can predict when the required new discovery will be made.

The specific examples just described offer a general area of great scientific promise—but one requiring a sharper focus. To illustrate, let's consider a few places where scientific progress is in the making.

Historically, understanding and knowledge of matter was first developed in diffuse form—for example, the kinetic theory of gases and the gas laws mark early milestones in scientific progress. Later more complex forms such as liquids yielded to study. Presently we are making great strides in understanding the still more complex interactions of matter in the solid state.

Further progress in this field certainly will hold important practical consequences. Energy conversion represents a promising area for solids. A few of the presently possible conversions; electricity can be changed to light, light to electricity, atomic radiation to electricity, heat to electricity, and electricity to cold.

Another area of solid-state progress with exciting possibilities is in the mechanical properties of crystalline solids. The role of defects in crystals and the remarkable properties of "perfect" crystals provides a hint of the great new knowledge to come from this research, inevitably affecting the world of mechanical things.

PLANNING DISCOVERIES

Now let's take a look at the second decade ahead. Because we cannot simply look around the laboratory and see the accomplished results upon which it will be based, this extension—from 1967 through 1976—is much more difficult than the one just discussed. Particularly, one should hesitate to guess about the gadgets of this future period, although scientists can generally tell you what scientific discoveries the gadgets of tomorrow will depend on.

For the most part, the basic scientific discoveries for this period have not yet been made. Just what they will be and when they will be is a somewhat speculative matter. There are some plausible reasons for thinking that in the future scientists may be able to do a better job of predicting scientific developments.

Increasingly, scientific discoveries occur in areas of human need; for today's scientist isn't completely at the mercy of a capricious nature. The tools of modern scientific research have become powerful indeed; and under the influence and pressure of a frontal research attack, an unwilling nature may frequently be made to yield a desired result. Generally speaking, you will find some validity in the statement that to an increasing extent in the future scientists will determine what discoveries need to be made and then plan to make them.

The plans will, of course, not always be successful. Mother nature has the final word and may cast a veto. But the question of the final outcome of a research investigation is becoming more and more subordinate to the practical questions of probable cost, time required, and the availability of required scientific skills to accomplish the research. This will probably be true to a progressively greater extent in the future. Scientists plan to make discoveries in areas of great opportunity and need, and the powerful tools and skills of modern research will implement the planning.

But don't get the impression that basic research and pure exploration on new frontiers of science will disappear. Presently and in the foreseeable future, these frontiers seem to be limitless; they will continue to provide an outstanding challenge to the mind of man. In applied research where you seek a specific objective, the variety and effectiveness of the scientific techniques that can be brought into focus on a given problem will increasingly bend nature to our will.

Projecting the future—at least the future that will be based on science and technology—looks relatively easy for the next decade. The second decade confronts us with the prediction of discoveries which have not yet been made, making only general outlines discernible. However, those general outlines will in substantial degree conform to human needs and wants, and scientific research will provide powerful tools for shaping this future.

Looking beyond 1976, the crystal ball really becomes clouded. Even a guess at what *research projects* will be 20 years from now would be presumptuous. The scientist just plain cannot and should not try to say what the world will be like in 2000 AD.

PROGRESS—A SURE THING

But the answer to "Will there be as much scientific progress during the second half of the 20th century as there was during the first?" is, "Yes, definitely. There should be *more* scientific progress between now and the year 2000 than there has been since 1900."

And this isn't inconsistent. Often a general question about the future can be answered but not a specific one. Ask if a shutout will be pitched in the National League on July 23 of this year, and the answer will have to be, "Nobody knows." But ask if there will be at least a dozen shutouts pitched in the National League during the 1957 season, and you will find plenty of baseball experts ready to say, "Yes, of course." Statistically, this seems to be a sure thing.

Similarly, great new scientific progress during the next four of five decades also seems to be a sure thing. Over the years, technological results have been produced pretty much in proportion to scientific efforts. You don't have to be acutely perceptive to assume that this correlation between research and progress will continue. Exactly *what* all this effort will produce cannot be foreseen, but *something* will be produced.

To justify great expectations for the future, you need only compare the scientific effort of the present with that of the year 1900. That year marks the beginning of the golden age of technological progress. But who would have guessed it from the amount of scientific research then being conducted?

If two men working on a flying machine in a bicycle shop constituted the promise of a multibillion-dollar industry 50 years later, what can you anticipate from the aviation industry's present research budget of nearly half a billion dollars annually? If "proton" and "electron" did not appear in most dictionaries published in 1900, how shall you compare progress in atomic energy during the past half century with what we can expect during a 50-year period starting with years when the annual expenditure on the atom alone reaches nearly $2 billion?

In no area do you find the difference or the future promise greater than in *industrial* research. Today, thousands of businesses—large and small—realize that they must invest in technological progress to meet competition. Many industries, some more than others, realize that new fundamental scientific knowledge represents as important a raw material as the tangible stuff from which products are made. But in 1900 industrial research as we know it now was non-existent. A handful of firms had chemists trying to improve products, although the word *chemist* was more closely associated with the drugstore—a place where, surprisingly enough, you purchased mostly drugs. *Physicist* was not only a word unknown to the general public—it was practically unpronounceable!

Let's try placing the history of research in some kind of proper perspective. One famous idea for organized research dates back 300 years: Sir Francis Bacon, in *The New Atlantis*, described a "college of research" called Salomon's House. Its purpose was to ascertain "the knowledge of causes and secret motions of things and the enlarging of the bounds of the human empire to the effecting of all things possible." However, many years passed before Bacon's prophecy began to be fulfilled. During the subsequent Age of Invention, man—who had been making inventions of one kind or another from the time he first lighted a fire—finally began to become scientific by collecting some fundamental knowledge about how nature worked and then applying logical processes of reasoning to these discoveries.

As early as 1875, the application of science to industry began to receive recognition—but little support—from industrial leaders. The discoveries of science made their way into industrial practice in a variety of ways. The inventor, alert to the latent potentialities of any new scientific discovery, combined the work of academic scientists with his own inventive talents. Thomas Edison, for instance, was a careful student of scientific literature in a wide variety of fields. But the use of science by industry was not organized. Industrial research really began about 1900, but in a very small way. Until 1915, the *Readers Guide to Periodical Literature* did not list industrial research as a subject.

EARLY INDUSTRIAL RESEARCH

The earliest growth of industrial research occurred in the industries that actually had been born in the laboratory or that were directly dependent on new knowledge for their growth. Even as late as 1920, the electrical, chemical, and rubber industries employed two thirds of all the research workers recorded in the first survey of the National Research Council. This first survey, taken in 1920, showed that about 300 laboratories were engaged in industrial research.

By 1940 the figures increased to more than 2000. The total number of people employed by the laboratories jumped from a few thousand to more than 70,000. The annual expenditure increased sharply to approximately $400 million. Even the depression failed to stop the march of research progress. Bankers, industrial executives, even stockholders took keen intrest in the research activities of their companies and became convinced that "research is the best form of industrial insurance." If historians feel that the word *phenomenal* best describes the growth of industrial research during this period, what word satisfactorily describes what has happened since 1940?

Fortune said recently, "Industry has been on a research *binge*." Nearly 3000 companies now maintain industrial laboratories and employ over 250,000 people, including well over 100,000 scientists and engineers. Today you can measure the expenditures in billions; last year industry spent $2.7 billion for research and development. Admittedly, this figure covers everything from the purest fundamental research to some fairly routine engineering. Also this phenomenal growth in total effort exists more in the areas of applied research and development than in the area of basic research—a matter of proper concern to many analysts of the present situation.

TODAY'S OUTLOOK

But even assuming that slightly less than 10 percent of the nation's total research budget of $4 billion—including government and academic research as well as industrial research—goes for basic research aimed at finding new fundamental knowledge, this figure still represents an almost unbelievable increase over the corresponding figures of 1900. Certainly the comparison provides a reliable back-

ground for optimistic future forecasts. Although you would probably agree that too small a segment of the total research and development budget finds its way to basic research, the growth of the entire circle has been so great that even a narrow slice of the pie contains considerable nourishment.

In view of the established correlation between research and progress, who will say that science cannot produce more in the next half century than it did in the last?

No specific predictions as to what life will be like on New Year's Eve, December 31, 1999 can be made. But the prospects are good. Scientific progress—if it continues to depend on the best in men's minds and to survive in spite of the worst—will provide things not found in today's wildest dreams.

I cannot guess how it will be, but I would certainly like to be here.

An important logistic development having civilian as well as military implications was recently made public. It is a portable oil refinery of 1000 barrels-per-day crude processing capacity. From this report, it is designed to produce 11,550 gallons of motor grade gasoline, 6300 gallons of aviation jet fuel, 7854 gallons of diesel fuel and about 23,000 gallons of residuals. In tests, the plant has exceeded the designed capacity by as much as 60%. Having an aggregate weight of 50 tons, the refinery can be dismantled into six basic components. The components are air transportable and can be erected and put into operation in two days after arrival at the site. Developed primarily for military use, the unit has commercial application in newly developed producing areas, particularly during the period before pipeline availability.

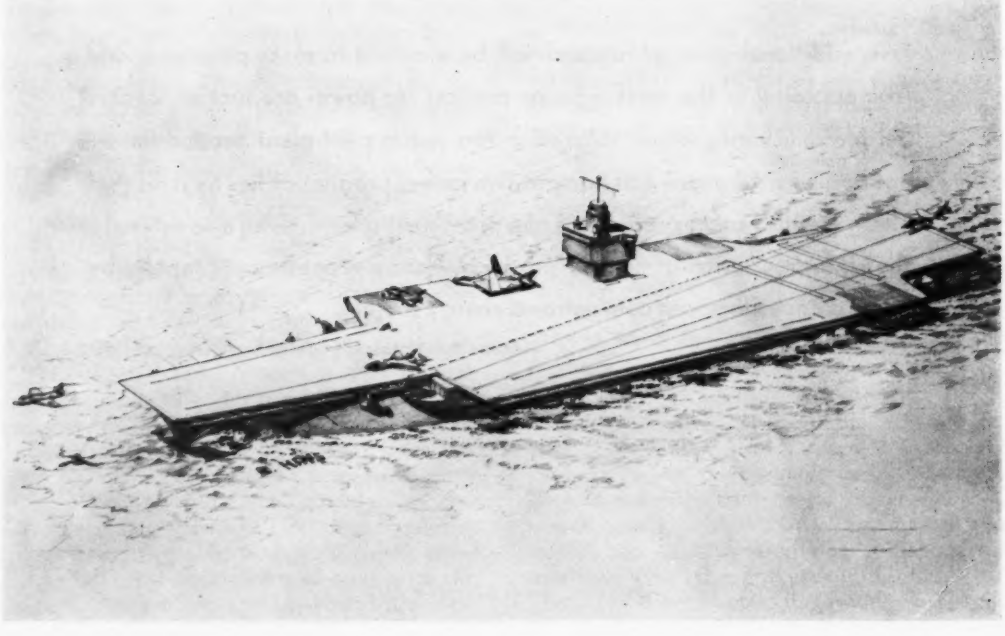
—from "Oil Forum" press release

Five additional years of research will be required to make possible a realistic appraisal of the nuclear fusion process for power production. Technical feasibility may be established in ten years; pilot plant production will not begin for 20 years, and competitive power production lies beyond that. These are the recent predictions of a prominent scientist who also estimates that the production of nuclear power by fission processes will rapidly become competitive with conventional energy sources.

—from "Mechanical Engineering," August, 1957

Figure 1 (left). USS *Ranger*, full bow view, approaching end of construction.
—Official U.S. Navy Photograph

Figure 2 (below). Artist's concept of the Navy's proposed nuclear-powered carrier, CVA-(N). CVA(N) will represent the most modern of a long series of attack carriers, starting with the USS *Langley* in 1922. One of the more important features of the CVA(N) will be almost unlimited steaming endurance at high speed. Operational flexibility will be increased also, as a result of this capability, since high speeds can be maintained without regard to conserving fuel oil; offensive and defensive capabilities will be improved and replenishment requirements much reduced. The aviation fuel supply will be double that of the USS *Forrestal*, and an additional 4,000 square feet of flight deck space will permit operation of additional and larger aircraft. The CVA(N) will be able to operate more efficiently during unfavorable weather conditions. The nuclear-powered carrier will not require smokestacks or "up takes" to carry smoke from her boilers. This will permit island configuration with new high-performance radar, and improved damage-control and other facilities.
—Official U.S. Navy Photograph



GEORGE LEGHORN

THE STORY OF SHOT PEENING

THE AUTHOR

is the Chief Metallurgist of the Belmont, California plant of the Western Gear Corporation. He is a graduate of the University of California in 1950 and holds a Bachelor of Science degree in Physical Metallurgy. He is a member of the American Society for Metals and the American Electroplaters Society. Mr. Leghorn desires that due credit be given Mr. John O. Almen who lent technical assistance and advice in the preparation of this paper.

The Society received permission to publish this paper, gratis, through the courtesy of Captain E. E. Sprung, U.S. Navy, Retired.

SHOT PEENING is a means of cold working the surface of metal parts by means of a hail or blast of round metal shot directed against the surface. It is equivalent to a myriad of small hammer blows impinged over the entire surface indenting the surface and causing plastic flow and work hardening of the surface metal. This work hardening of the surface metal increases its tensile strength and yield point and a small percentage of the beneficial results of shot peening are attributable to this effect. The greater benefit, by far, however, results from the fact that the surface metal is upset and put into compression; the surface compressive stress is extremely beneficial in obviating fatigue failures. What fatigue failures are and how shot peening helps to eliminate such failures will be dealt with later on.

Shot peening is a fairly recent renovation of a very ancient art and in order to have a clear conception of what occurs in the peening process, it might be well to go back in history and consider some of the early aspects of cold working or, as it would have been referred to in olden days, hammer hardening. In the Iliad, the Greek chronicler, Homer, refers to copper breast plates and spear heads and very poetically describes how some spear points penetrated the breast plates with ease while others merely bent on striking and fell to the ground without more than denting the armor of the wearer. The connotation of his writing is that some mystic force had permitted the spear of one warrior to penetrate the breast plate of his enemy while, in the other case, the armor of one would bend and turn aside the spear of his enemy.

Believe me, it wasn't the power of positive thinking that drove the spear head into the armor in one case and caused the armor to bend the spear head in another. It was the plain old fact that the reliable armorer knew from practical tests that cold hammered weapons and breast plates were harder and stronger than those which had been placed in a fire. The intuitive mystic, on the other hand, was so enthralled by the supposed merits of fire that his last operation was to heat the metal and thus anneal or soften it. Also, the unreliable armorer may have been smart—but lazy. He observed that the longer he hammered the copper, the harder it became to form it to the desired shape and he knew that by heating it, he could restore the softness and ductility and thus make his job easier. By annealing just previous to the final light taps of the hammer, he left the armor or spear head soft and probably cost the life of his customer.

If copper is hammered too much, it can become brittle and subject to cracking; however, it takes a lot of hammering to do this. It does show, none the less, that the armorer had to use experienced judgment in forming a spear head from a rough block of copper. First, he had to fire treat it (anneal) to make it soft and ductile and receptive to hammer forming. He next hammered it to rough form and then reannealed it to remove the hammer hardness prior to the final hammering of the spear point to its desired shape and strength. Knowing just how far he should carry his first hammer forming and annealing so that final shaping by hammer would give the weapon excellent hardness and strength without brittleness, called for a lot of experience and judgment on the part of the armorer.

A modern metallurgist would measure the increase in hardness and strength of the copper for measured amounts of cold working and then determine, by actual controlled tests, which percentage of cold work gave the optimum results for the use intended. If this happened to come out to say 20% reduction of metal thickness by cold rolling, the metallurgist would then specify a 20% cold roll reduction of the copper and the Quality Control Supervisor would set up an inspection procedure to assure that this was adhered to. As you can see, we haven't made any basic changes over the ancient armorers' methods, but we have developed standard methods (cold rolling in this instance), standard tests to determine just how much cold work to give the part, and standards of quality control to assure reproductibility. Modern man's achievement, in this and many other ancient arts, has been to take the guess work out of the operation.

Another historical use of cold working which is more directly analogous to modern shot peening was the old time blacksmith's art of hammer peening the tension side of carriage springs. He found out that if he bent the flat carriage spring in the same manner that it would be bent as part of a loaded carriage and then ball peened the convex (tension) side while bent, he could improve the life of the springs even for greater loads or when smaller springs were used. Today, we call this "strain peening" and some of the increases in service life of parts so treated are phenomenal. The old time blacksmith merely knew from past experience that it worked so he went ahead and did it. His shot was as big as the ball on the ball peen hammer he used. The striking intensity depended on the mass of the hammer and the strength of his muscles, modified of course, by whatever good judgment he had managed to accumulate from past experience. His peening rate was one indention at a time so one would suspect that a large ball was used to cover as much area as possible per blow and thus save some time. Any craftsman who was proud of his work would add the peening operation; however, he could hardly afford to use all of his day just to improve a few springs.

Here again, we have added but little to the art as used by the blacksmith. We have, however, greatly increased the scope of usage and our knowledge as to why of its effect. More than that, we have set up standard means for doing the same thing with a hail or blast of small, well rounded shot of specific hardness—we have developed means of specifying how to do a given job and we have set up controls to insure duplication of results.

MACHINES FOR SHOT PEENING

Machines for shot peening fall into two distinct categories. One is the wheel type machine wherein a bladed wheel rotating at high speed is gravity fed with peening shot and sprays this shot onto the work by the slinging action of the blades. The second is the air blast type machine wherein the shot is impelled onto the work by means of a blast of pressurized air.

The wheel has the advantage of emitting a terrific hail of high speed shot and thus greatly shortening the peening time necessary to gain the desired result (arc height). Due to the high speed and great volume of shot thrown, the work must necessarily be confined and fixtured in a cabinet. The resulting wear on the impeller blades, cabinet walls and fixtures can be excessive. Fixturing is also more difficult than with air blast machines and the cabinet limits the size of the part to be peened. Large wheel type machines are initially very expensive but a great many are used where there is sufficient production of the same types of items to constantly feed thorugh the machine. The wheel type of machine is generally cheapest for large volume production.

The air blast machines vary as to method of feeding the shot into the air blast. In some, the shot is sucked up by the vacuum caused by the aspirating action of the blast; in others the shot is gravity fed into the air stream and some types have pressurized air to feed the shot into the air blast at the same pressure. Such machines are usually of the cabinet type, although a good many are utilized in a sealed room. The great advantage of the air blast machine is its versatility. The nozzle can be directed onto the work as required instead of having to fixture and position the work in a wheel blast which cannot be directed. For peening individual parts or short runs of the same part (say up to 50 parts), the air blast types are far superior and cheaper to operate than the wheel types.

I would like to mention here the superior advantages of the Vacu-Blast method for some types of work. This applies particularly to work which is round in nature and which must be peened on the periphery. Examples would be large gears to be shot peened on the teeth only, or long torsion shafts or pipes which are to be peened over its entire surface. Due to the shot pickup principle incorporated in the Vacu-Blast design, it is not necessary to carry out the operation in a cabinet or sealed room. Although a small amount of shot will accumulate on the floor, it usually is less than will escape from a supposedly sealed cabinet of a wheel type machine. The most important feature of the Vacu-Blast pickup nozzle is the ease with which it can be applied to the type of work mentioned. A large gear, for instance, can be set up on a trunion and rotated while the blast nozzle is traversed across the gear face. Variations of traversing speed (a variable speed motor should be used) and blast nozzle air pressure will give a correct combination of arc height and coverage. (Note: These terms will be defined later.) In a like manner, a long torsion bar or oil well drill pipe can be surface peened merely by rotating the shaft or pipe on centers and traversing the blast nozzle along the length of the work. Here again, the speed of traverse and blast air pressures can be regulated to give the desired coverage and arc height.

TYPES OF SHOT USED FOR PEENING

Peening shot can be purchased as such from a good many companies. It is well rounded and screened to definite size ranges. It used to be assumed that the shot hardness had to be equal to or greater than the hardness of the metal being peened. Under these circumstances, the only shot available to peen carburized parts or tool steels having a hardness of 60 R_c was chilled iron which has a hardness of about 63 R_c. However it has been found that heat treated steel shot having a hardness of 46 R_c is just as effective, as far as increasing fatigue strength is concerned, as is chilled iron. Steel shot is more expensive initially than chilled iron; however, the brittle nature of chilled iron causes it to break up very rapidly and, in fact, it has but one fourth to one sixth the life of steel shot. Chilled iron also presents a major separation problem since shot peenings specifications require that broken shot be separated and eliminated from the peening shot. Steel shot is therefore much cheaper in the long run; it is cleaner to handle and causes much less wear on cabinet walls, wheels, nozzles and fixtures.

Cut wire shot is another material used for peening; however since it is manufactured by clipping off short lengths of steel wire, it is, initially, not round and has sharp edges. Peening specifications require that this type of shot be blasted against scrap steel until it rounds out and this process, besides being time consuming, decreases the shot life. It is suggested that round steel shot be used for all peening operations on steel parts. By purchasing it, as such, much time and trouble will be saved.

It might be well to add here that a number of authorities in the shot peening field prefer cut wire to cast steel shot and John Almen states that cut wire can be used as cut on hard metals such as carburized parts and that he personally prefers clipped wire to so-called steel shot for peening steel hard enough to resist serious notching.

Clipped wire has the advantage of uniformity of mass (due to clipping off definite lengths from wires of uniform diameter) that cannot be achieved by screening cast steel shot. Conditioned, rounded by previous blasting against a hardened surface, clipped wire shot can be purchased and it is common practice to peen with this material and to make small additions of the unconditioned clipped wire shot as the original shot load diminishes due to wear or dragout. Actually, the size uniformity claim is somewhat obviated by the fact that the shot wears and becomes smaller in use and the lower limit of size is finally dependent, as with cast steel shot, on the efficiency of the dust removal system.

Some interesting experiments have been carried out concerning the effect on arc height which occurs by use of new conditioned clipped wire shot each particle of which has a definite mass. As a matter of idle speculation, one cannot help but wonder at the mass of research data that would be available on duplexing (the use of two or more shot sizes in different ratios as to quantity of each) if shot was available only in precisely definite increments of size. This variable may or may not be important and a great deal of research remains to be done on it.

Nonferrous metals can be peened with balls of nonferrous metals, or nonmetallic materials such as glass, plastics and the like. Generally speaking, aluminum would be peened with aluminum shot.

John Almen states that "some nonferrous metals can be damaged by peening with steel or iron shot because serious electrolytic corrosion may result from embedded iron particles and that this is particularly serious in magnesium." It might be well to note that soft metals such as magnesium and aluminum can be effectively peened with glass beads. In peening stainless steel with steel or iron shot, care should be exercised to make sure that any embedded shot dust is removed from the surface of the part by a post chemical treatment (passivating) since such particles can materially decrease the resistance of stainless steel to corrosion. It is, perhaps, a not too well known fact that stainless steel, the surface of which has embedded iron particles from such sources as an iron contaminated grinding wheel or iron oxide particles from buffing compounds, is prone to rusting. Many puzzling occurrences of rusting in stainless can be attributed to this effect and a good post passivation treatment can obviate the trouble.

SHOT PEENING VARIABLES

Peening rate and arc height attained can vary with shot size, shot hardness, shot speed, quantity of shot thrown per second and angle of impact.

Shot size is specified as having a diameter which is one half, or less, the radius of the smallest fillet or surface irregularity of the critical area being peened; therefore, if a part having a one sixteenth inch radius fillet is to be shot peened, the largest shot that should be used would have a diameter of one thirty second of an inch or less.

Shot hardness for practically all steel (ferrous) parts can be 45-50 R_c. In other words, a round, heat treated steel shot can be purchased and used effectively for all peening operations on steel regardless of hardness.

Speed of shot can be changed by regulating the air pressure or, in the case of a wheel, the wheel speed should be adjusted until the arc height and coverage required can be attained (to be discussed later).

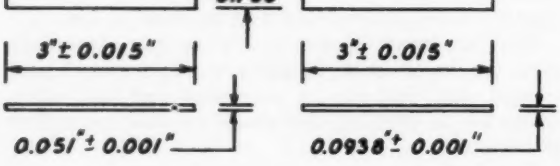
Quantity of shot thrown is important only with respect to the amount of time it takes to do a peening job. If you can throw a lot of shot at a definite speed, the job can be finished in a shorter time. (More peened parts per hour).

The shot blast should strike the surface being peened as nearly vertically as possible; however, it is seldom that this can be accomplished in actual practice since the blast may be directed at a groove or fillet. It is common practice to peen such surfaces

as though the bottom only was being treated and to accept the results due to peening some areas at an angle to the shot blast. In other words, it isn't worried about too much except in very critical areas. In very critical parts (those which are subject to rapid fatigue failures) every attempt should be made to direct the shot blast perpendicular to the surface subject to the highest loading (the point where the part has been failing). Some reduction in shot effectiveness can occur due to shot rebound when the blast is directed normal to a surface. This is particularly true in centrifugal machines.

STANDARDS OF MEASUREMENT FOR SHOT PEENING

For purposes of standardization, quality control and reproducability, some form of measurement must be set up for any specific process and, for the process of shot peening, the standard of measurement is arc height. This means of measurement was devised by John Almen while at the Research Laboratories Division of General Motors and the test strip used along with the dial gage for measurement are called the Almen Strip and Almen Gage. This test is based on the fact that a sheet of metal which is cold worked on one side only (as by shot peening) will deform, due to the compressive stresses set up on the cold worked side, and form a bow or arc (hence—arc height) with the peened side being convex. The more the peening the greater the arcing, up to a certain point. Almen standardized the sheet of metal used, both as to size and physical characteristics as follows:



These strips of SAE1070 cold rolled spring steel are heat treated to 44-50 R_c and must have a flatness of .0015 arc height as measured on the Almen Gage. It should be noted that practically all test strips purchasable today are about 46-48 R_c and within 0.0005 arc height.

These strips are mounted on an Almen Block (Strip holder) which is usually carburized and hardened or made of heat treated tool steel to give solid backup for the strip and, primarily, to prevent damage to the block by continuous exposure to the shot stream. It should be noted that a soft steel block will give the strip the same arc height as a hardened block for the same shot peening exposure; however, after a dozen or more test exposures, the soft steel block will be badly indented and may need replacing. Almen blocks can be purchased but, in a pinch, a soft steel block can be made up for use. Dimensions and shapes of the Almen block and gage can be found in the SAE Manual on Shot Peening.

In use, this block, with secured Almen strip, is solidly placed at the same position with respect to the blasting nozzle or wheel as the work it simulates. In the case of a gear, the Almen block would be attached to a dummy or scrap gear of the same dimensions as the one to be peened. The attachment can be made by use of the same screws that hold down the strip. For short runs, a flat would merely be milled onto the gear surface and this flat would be drilled and tapped for the hold-down screws. The Almen strip would then be attached directly onto the milled surface for peening trials. The thing to remember is that you are peening the roots of the gear teeth so the Almen strip should be at the same distance from the nozzle as the root. The shot blast would be directed vertical to the root surface and peening would take place as the gear rotated on a spindle thus peening all of the gear teeth. In the case where the shot pattern (area of shot blast coverage on the peened surface) did not cover the full length of the gear teeth, the nozzle would have to be traversed down the length of the tooth while the gear is rotating under the blast thus assuring that all of the tooth surfaces are peened.

It is sometimes convenient, for field work, to tack weld a flange on to the Almen block so that the block can be "C" clamped onto any kind of a jury-rigged frame so as to hold it at the necessary distance from the blast nozzle. In other words, a dummy gear doesn't have to be a full gear but merely an extension from the rotating device (as an arm) on the end of which the block could be attached (by tack welding or screws) so that the Almen strip is at the same distance from the rotating center as would be the roots of the gear teeth.

I made mention, previously, of the necessary distance of the work being peened from the nozzle orifice. This distance can be any that is required to do the job. The thing to realize is that the closer the nozzle, the more intense and rapid is the peening action; however, the shot pattern is very limited in area and this necessitates moving the work or the nozzle or both around so as to cover all of the surface to be peened. If, by moving the nozzle 3 or 4 inches farther away from the work surface the blast pattern would cover all of the surface to be peened, then this would be the simplest procedure; here, however, it would be necessary to prolong the peening time to achieve the necessary arc height and coverage. (Coverage is the percentage of peened surface actually indented or struck by the shot. If 5 per cent of the surface of the Almen strip used in the test run, or the actual surface peened, was unin-

dented by the shot then the coverage would be 95%).

Before going on to why we would peen to a certain arc height and how we would set up to accomplish this, I wish to clarify exactly what a specific arc height means and the "A" and "C" strips.

Suppose we have a Government or other specification that reads "The part will be shot peened on area as shown in accompanying print to .016A2." This merely means that the Almen #2 (2 for #2 gage) gage will be used (there used to be an Almen #1 gage but its use has been discontinued so there is actually only one measuring gage to worry about). The A stands for the Almen A test strip and the .016 is the actual thousandths of an inch that the dial gage point can advance due to the curvature of the A strip by peening. The dial of the gage reads in units, as 1, 2, 3, 4, 5 etc., but these are actually thousandths. Therefore, .016A2 means a 16 reading on an Almen A strip when a number 2 gage (the only gage in use) is used. A specification of .010C2 means a 10 reading on a C strip must be attained. Since the number 1 gage has been discontinued, you will often-times find designations of .018A or say .012C. The number 2 gage is inferred in such a case. You may even see specifications as 14A and this merely means .014A2.

The A strip is used up to arc heights of .024A2 and the C strip above this reading. There is a direct 7 to 2 ratio between A and C strip readings, that is, an .024A2 reading would be equivalent to 2/7 (.024) or .007C2. The A strip is used between .004A2 and .024A2 and the C strip from .007C2 to .020C2. Shot peening intensities above .016C2 are seldom if ever required and most parts would be over peened at this arc height.

One thing to remember in measuring arc height is that the smooth or concave side of the peened strip should be placed against the gage so that the surface roughness will not effect the reading.

A published rough guide as to what arc height to peen parts to is based on the thickness of the part and is tabulated as follows:

Thickness of Part	Arc Height
1/16"	.004A2
1/8	.008A
1/4	.014A
3/8	.018A
1/2	.021A
5/8	.007C
3/4	.008C
7/8 or greater	.010C

In actuality, 80% of all shot peening is held in the range of .010A2 to .020A2 and even fillets of ½" radius on a 4" diameter shaft are usually peened to .018A2.

John Almen gives considerable insight into the art of adjudging specifications for peening by his statement that "in peening clean, uniform parts, it is not necessary to use high intensities since all that is needed is to avoid surface weakness. Rough forged or other parts, which may be decarburized or scaled should be peened with sufficient intensity to reach deep uniform metal."

The tolerance on peening to a specified arc height is ± .002, therefore, a spec. of .016A2 means .014A2 to .018A2 and .010C2 would be satisfied by an arc height of .008 to .012C2.

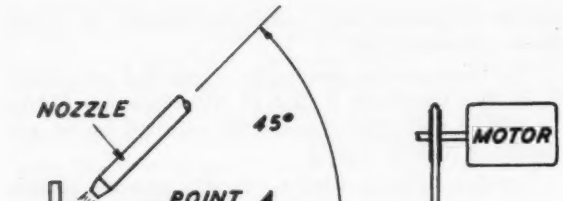
I wish to point out here why shot peening specifications are sometimes so haphazardly applied. There is a correct scientific way to arrive at an arc height specification for any particular part and the procedure is to shot peen a series of groups of the same part (usually 3 or 4 to a group) to definite intensities in steps. The parts of each group would be peened to the same arc height and the groups would be peened to say .006A2, .010A2, .014A2, etc. These parts would then be run to destruction in field or simulated field tests and the arc height conforming to the group which gave the longest service life would be specified.

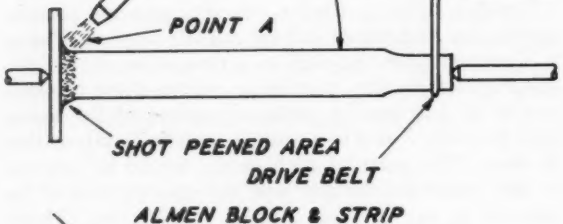
The drawback here is the extreme expense of such tests and that it must be done on every component which is prone to service failure since the peening intensity which gives optimum life on one part will not generally give optimum life on another part. To counter-balance this we have the factor that shot peening a part by guess will generally give a very advantageous increase in fatigue life, and it is readily realized that it is much cheaper in the great majority of cases to peen between .012 and .018A2 and accept the increased service life resulting from this treatment than to try and get optimum results. With respect to "guess peening" deep peening will reduce the "hazard," if any, of this process. Some parts, however, have been scientifically tested to establish the optimum shot peening conditions and any manufacturer who has expended such a large amount of money to establish this arc height has a bonafide right to demand that his parts be shot peened under controlled conditions and to precise arc heights. On this basis, and the basis that all manufacturers want quality control to guarantee the uniformity of their product, we will discuss the method of controlled shot peening to meet a definite specification.

SHOT PEENING TO SPECIFICATIONS

The first step is to provide a fixture to support the Almen block with its test strip so that its position simulates the critical surfaces to be peened.

Second, a guess is made as to the peening conditions that will be necessary to meet the specification. As an example: say S330 tru-steel shot is used at an air pressure of 50 pounds and the nozzle is positioned 3 inches from the surface to be peened. As a specific example, let us assume that the work is a main drive shaft 3" in diameter with an integral coupling flange 8" in diameter on one end and that the area to be peened is the radius (fillet) where the shaft becomes the flange as shown in sketch. Assume .016A2 is the spec. (See following drawing):





FIXTURE OF PIPE OR SOLID ROUND

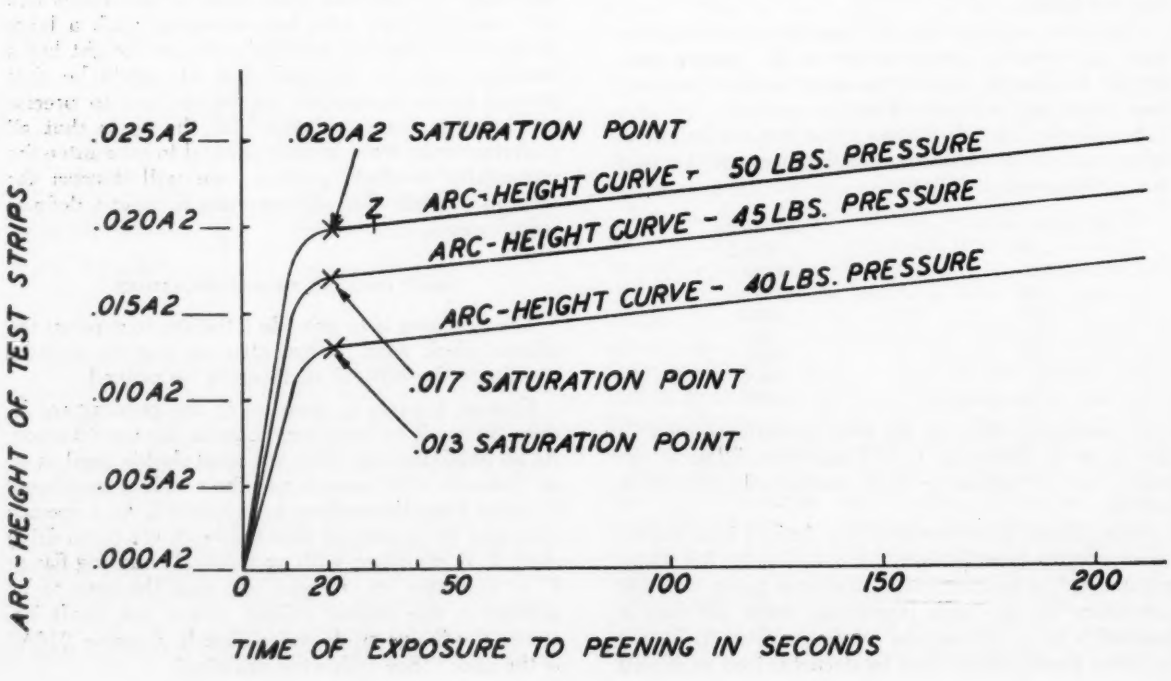
A dummy fixture (shown in lower part of drawing) would be made up which would rigidly hold an Almen block so that the distance from the center of rotation to the test strip would be the same as the distance from the axis of the shaft to point A which is halfway up the fillet. The block would be positioned so that its surface was at right angles to the blast stream when directly under it (45° angle to the axis of rotation). The fact that the ends of the Almen strip will come closer to the blast nozzle due to the block being flat instead of round is overlooked since tests are based on this arbitrary positioning in the first place. The position of the block should be the same as was originally used in deriving the specified arc height. If no derivation tests were originally run, the positioning described would be used.

Thirdly, using the setup described a shot peening (arc height) curve is determined. This is done by running (unpeened) new Almen strips for specific periods of time such as 5, 10, 15, 20, 25, 35, 45, 60, 90 and 120 seconds. The arc height on each strip is taken on the Almen gage and these arc heights are graphed against the corresponding time as shown.

Such arc height curves are very characteristic. They go up steeply at first then rapidly change to a much more gentle slope. The point X, just to the right of the slope change is called the saturation point and this is the degree to which such shot peening should be carried.

Say our first try gave us an arc height at the saturation point of .020A2. We would then decrease the air pressure to some lower value, say 40 pounds and rerun the curve. If the saturation point on the graph of this run came out as .013A2, we would increase the air pressure to, say 45 pounds and rerun the test. Say the saturation point came out at .017A2. Since the spec. is .016A2 (.014-xO18A2) we would be in tolerance and we would then examine the Almen strip at .017A2 to make sure that the coverage was as specified or better.

Coverage is usually specified at 90% minimum. If the time for the .017A2 strip was 25 seconds at 45 pounds pressure, we would polish the side to be



peened on a new Almen strip and then shot peen it at this setting. The strip would be removed and examined under a magnifying glass and an estimate of the coverage (indented surface) made. In nearly all cases this will be above 90% at the saturation point. If it is not, we would repeat the foregoing tests using a smaller size shot and would find that we could get above 90% coverage by using say 40 pounds pressure and a peening time of 45 seconds to give us a saturation point arc height of .016A2.

We would then be ready to start controlled production peening to specification. Using the smaller size shot, a shaft would be loaded into the rotation fixture and peened for 45 seconds at 40 pounds pressure.

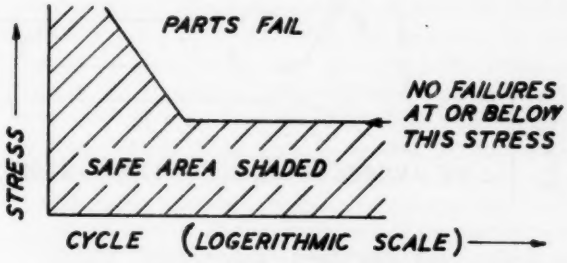
It would be well to point out at this point that, whereas our peening time here is 45 seconds, it would take at least four minutes of peening time to overpeen and, even then, it would not be damaging but would merely start to detract from the benefical increase in fatigue life already gained. It is oftentimes the practice, therefore, to peen beyond saturation to some point (Z) on the curve thus giving assurance that the saturation point has been reached and complete coverage effected. In doing this, we have increased the peening time so, to prevent the arc height from going over spec (.018A2), we decrease the air pressure slightly to compensate. I might add that this is fairly common practice; however, with a little experience, you will find that peening to saturation is not difficult and this should be the technique used.

FATIGUE FAILURES

We have repeatedly stated that shot peening greatly extends the fatigue life of metals. The definition of fatigue taken from the ASM "Metals Handbook" is as follows: "the tendency of a metal to break under conditions of cyclic stressing considerably below the ultimate tensile strength."

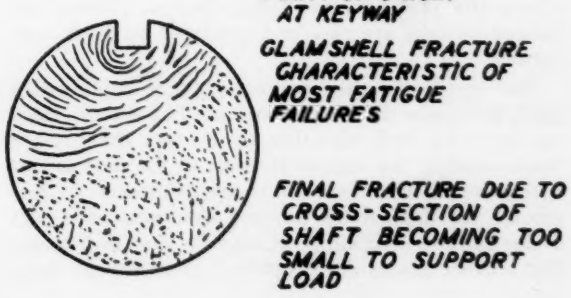
To quote Robert Burns, "The Best laid plans of mice and men gang aft aglae." Here we have a case of mankind using his scientific knowledge to find out the strength of steel in p. s. i., calculate the loading produced on a steel member in a machine and then very wisely designing the member out of steel so that it would take all of the loading it would get. Being of a cautious nature, he made the member at least 50% stronger than his tests and calculations said it had to be. This is known as a "factor of safety" and is a clear acknowledgement that mankind isn't too sure of himself. It's rough on a design engineer to find out that his liberal pad of protection wasn't liberal enough in the long run. The machine performed beautifully for awhile. Then the member busted; though this "failure by fracture" usually had the aggravating habit of occurring after the guarantee period had passed.

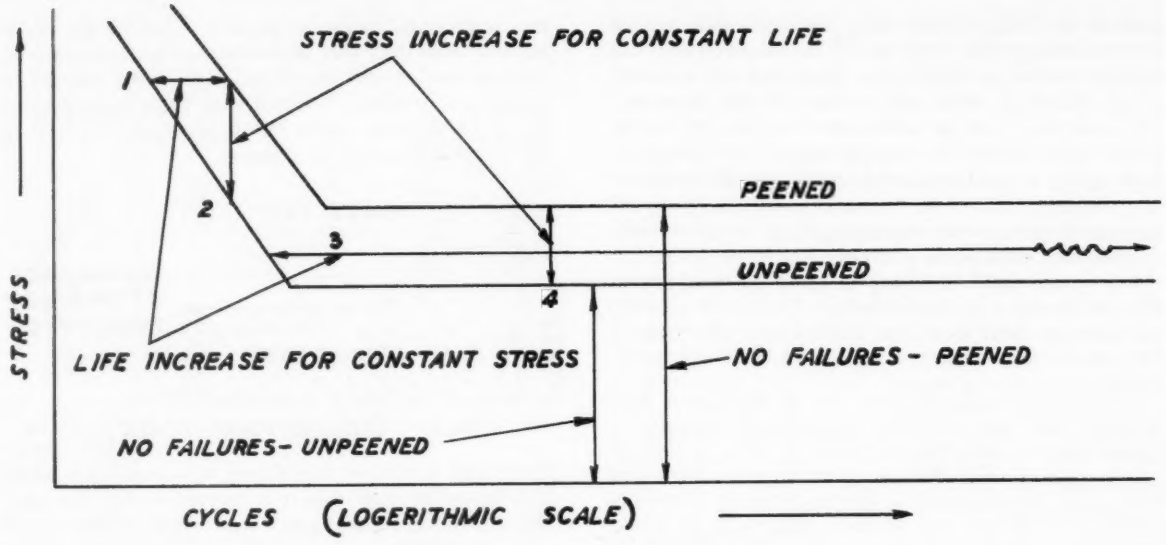
It is easy to visualize the amount of soul-searching and recrimination that took place in the engineering world. It wasn't just one machine that broke but a lot of them. The engineers knew something was wrong and began to wonder if maybe the static loading tests they had performed so meticulously on bars of steel might be inapplicable with respect to machine in motion. To cut it short, this proved to be the right answer and a lot of research resulted in the fatigue diagram as follows:



10,000,000 cycles on this diagram is considered as an indefinite life span. Up to a certain stress (horizontal—no failure line) you could cycle stress a part over 10,000,000 times and it would not fail. Above this line you could cycle it for say 200,000 cycles and then it would break. At a still higher stress (less than the ultimate tensile strength as determined by static loading) the part could fail in 1000 cycles or less. The result is, that for reciprocating, rotating or vibrating parts, we no longer design on the basis of static tests but on the basis of fatigue tests.

Parts which fail by fatigue are fairly easily recognized both by the origin of the failure and the clam shell markings over a part of the fractured surface. Such failures generally originate at a stress riser which can be a fillet, hole, keyway, forging lap, punch mark, seam, corroded area or steel having variations in structure (as hard spots). Failure originates at one of these points and a crack gradually works into the part. It should be realized that the part still has ample cross-section to sustain the loading under static stresses and, therefore, does not fail until the cross-sectional area has been reduced to a point where it can no longer sustain the applied load. It then fails suddenly. The part (area) which lets go all at once has a crystalline appearance, whereas, the area which failed over a period of time has a clam shell appearance resulting from the rubbing action of the surfaces on each other as illustrated in this diagram:


POINT OF ORIGIN AT KEYWAY
CLAMSHELL FRACTURE CHARACTERISTIC OF MOST FATIGUE FAILURES
FINAL FRACTURE DUE TO CROSS-SECTION OF SHAFT BECOMING TOO SMALL TO SUPPORT LOAD



HOW SHOT PEENING INCREASES FATIGUE STRENGTH AND LIFE

Shot peening, in effect, raises the demarcation line on the fatigue diagram as shown above.

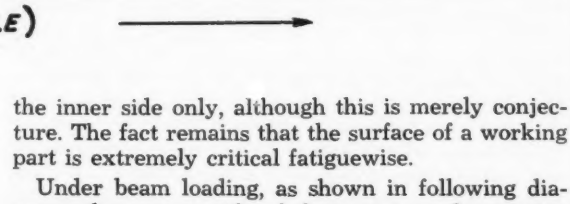
This diagram is from the SAE Manual on shot peening and is, of course, idealized for demonstrative purposes. It can be seen, that for the stress (load) at point 1, the service life of the part would be almost doubled and at point 2, for the same service life, the load on the part could be increased by about 40%. Point 4 would allow an increase of loading of about 50% without failure and a part that would fail within say 200,000 cycles at point 3 would last 10,000,000 cycles or more if peened. It can readily be seen from this diagram why some parts when shot peened can have a hundred fold increase in service life over critically loaded unpeened parts.

WHY SHOT PEENED PARTS RESIST FATIGUE FAILURE

In about 90% of the cases, fatigue failures originate at the surface of the part at some point which acts as a stress raiser. A few failures originate at subsurface defects such as slag inclusions, porosities, flakes, or the like, in the steel. This is particularly the case where the surface is in compression due to shot peening, nitriding, carburizing, or the like, and where the part is very highly loaded. Subsurface fatigue failures are rare and need not be dealt with further.

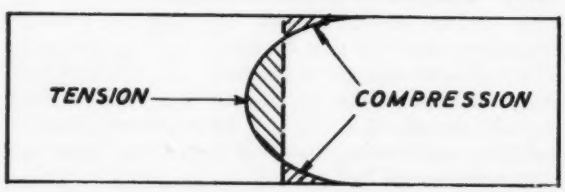
The surface is the weakest part of a structure since it is here that imperfections that act as stress raisers occur and, also due to the fact that, under beam loading, the tensile stresses in the part are at a maximum. Even so, these explanations do not wholly account for the surface weakness of a part under fatigue conditions. It may be due to the fact that surface grains are supported (buttressed) from the inner side only, although this is merely conjecture. The fact remains that the surface of a working part is extremely critical fatiguewise.

Under beam loading, as shown in following diagram, the convex side of the part is under tension (undesirable) and the concave side is under compression (desirable):



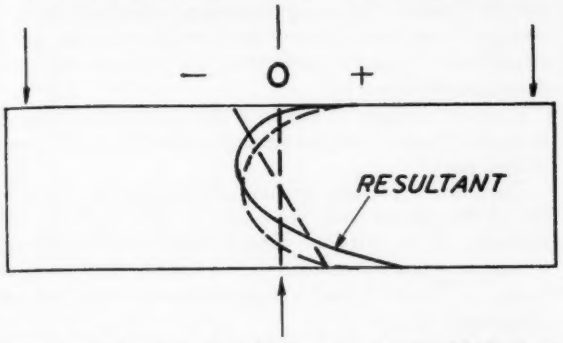
The same part, when shot peened overall in the unloaded condition, has its surface in compression due to the cold working and plastic upsetting of the surface metal by the hail of shot. Since the surface is in compression, the core is in tension to balance out the forces as shown in following diagram:

STRESS IN A SHOT PEENED PART



If the shot peened part is beam loaded, the stress which results is an additive combination of the stresses due to beam loading and the initial stresses

due to shot peening as shown in following diagram.



The resultant stress shown as a heavy black line shows that the surface of the part is still in compression even on the convex side of the beam loaded part and fatigue failures do not occur in a compressed area. The center is under a high tensile stress; however, it is no where near as detrimental here as it would be at the critical surface. We can load the bar beamwise until the convex surface of the peened part is in tension but this tensile stress would be far less than it would be if the part were not peened and would probably be well within the fatigue strength of the material. The surface compressive stress set up by shot peening counteracts the tensile stresses set up by beam loading and thus brings the surface metal into the safety area of cyclic stress loading.

OTHER USES OF SHOT PEENING

As mentioned before, shot peening is primarily used to increase the fatigue life of cycle stressed parts; however, there are a good many other fields which can derive unique benefits from shot peening. These will be listed and discussed numerically.

1. As an aid in prevention of stress-corrosion cracking.

This form of failure was originally called Season Cracking and, whereas it has existed as long as mankind has worked with metals, it was attacked as a metallurgical problem after British troops in India began to experience a rash of failures of brass cartridge cases. These cases were inspected on arrival and were supposedly sound; however, during the seasonal wet weather characteristic of the Indian monsoons, the cartridge cases would split open without even being fired. Metallurgical sleuthing revealed that these cases were cold drawn and that surface tensile stresses were set up during the process. It was also found that most metals and brass, in particular, would readily crack when such parts were exposed to corrosive media or conditions such as the hot, humid monsoon climate of India. The solution to the problem was to anneal the cases to relieve the damaging surface tensile stresses which were locked in by mechanical working of the metal.

John Almen gives another version of the name, Season Cracking, to the effect that brass carriage lamps had a tendency to split open during the early summer season and subsequent investigation revealed that it was due to the corrosive attack of ammonia generated by barnyard manure piles.

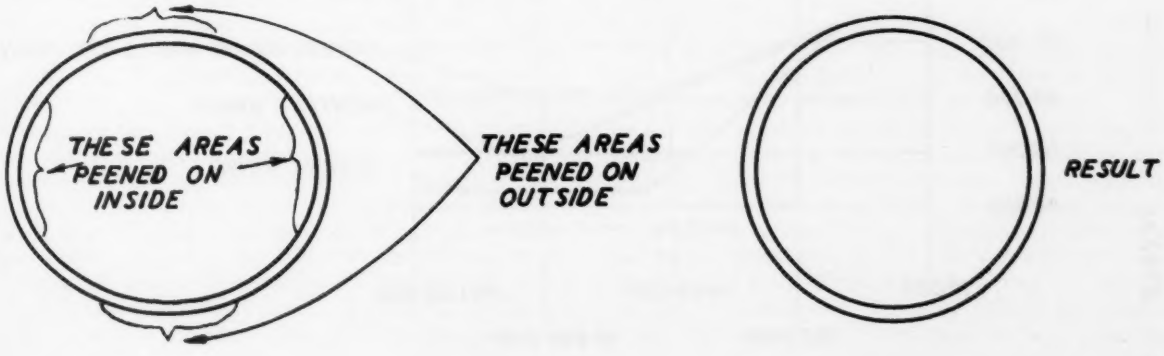
As mentioned, annealing will obviate this form of failure; however, shot peening has also been used to correct the defect. Shot peening counteracts the surface tensile stresses by superimposing surface compressive stresses which are not subject to cracking under corrosive condition.

2. As an aid in eliminating fret-corrosion failures.

Metal parts which fret (periodically rub or impact) against each other under corrosive environment are subject to pitting and disintegration. Since surface compressive stresses in parts subject to such failures will greatly ameliorate the condition, shot peening is resorted to as a corrective measure. This is particularly true on aircraft parts.

3. Straightening of parts by shot peening.

An Almen strip bends (arcs) due to the compressive forces and metal upsetting caused by peening. This same effect can be used to straighten parts which are fairly thin or quite large compared to their cross-section. For instance, large fairly thin (¾″ thick) ring gears which were considerably out of round have been selectively shot peened to bring them within a .003″ out of round tolerance. As an exaggerated example, we will use peening to round out a steel hoop which is elliptical in shape. Automobile axle shafts can be straightened out by peening after heat treating with life increases of more than a hundred fold.



4. Peen-forming.

Peen straightening is actually peen forming; however, in the aircraft industry, whole wing sections are given camber (wing curvature) by selective shot peening. You could visualize the original plate as being a large Almen strip which is shot peened at a variable intensity over its surface to give a variation in curvature. This forming could be done by dies; however, the convex surface of the part would have a detrimental surface tensile stress which would be prone to failure by fatigue or stress-corrosion attack. By shot peening, the peened (convex) surface is put into compression by the plastic upsetting of the surface metal while the opposite (concave) surface also is surface compressive (concave side of a bent part is in compression).

Saw manufacturers and saw filers form circular saws by peening. A very old art. They do not use small areas of impact but hammers having large radii of curvature. Another such use is the hammering of piston rings to make them open up. By doing this, they have to be closed in, compressed, to fit into the cylinder barrel and assume their original true circle shape when so compressed. Were these rings merely flex bent outward, they would yield at the weakest point and would not resume a true circle form on being pressed into the cylinder.

5. Shot peening as a corrective measure for grinding defects.

Ground metal surfaces are generally in a surface tensile state due to upsetting of the surface metal by the heat generated in this process. Severe grinding with a loaded or dense wheel will generate so much surface heat and upsetting that the surface will actually split, on cooling, due to the exceedingly high tensile stresses set up. These grinding cracks look much like the craze pattern on a sun-baked sheet of mud and are caused by the same forces. As a sheet of mud, left from a dried pond or puddle, dries, it shrinks due to evaporation of its contained water. This shrinkage sets up tensile stresses and the mud sheet develops a crack pattern when these stresses exceed the cohesive forces between the mud particles.

Shot peening counteracts these deleterious surface tensile stresses by superimposing a higher surface compressive stress. Below is a rough graph of some experimental results conducted on ground and shot peened specimens.

6. Shot peening of parts prior to chrome plating to correct loss of fatigue strength inherent to chrome plated parts.

Chromium plating greatly decreases the fatigue life of the plated part; however, by shot peening the surfaces to be chrome plated prior to the plating operation, this defect can be obviated. On the next page is a graph, based on experimental work, which illustrates this.

7. Peening as a means of testing the adhesion of electroplates.

Such articles as silver plated aircraft bearings require excellent adhesion of the electroplated metal to the base metal and this adhesion can be checked on a control basis by shot peening a selected precentage of the silver plated bearings. If adequate adhesion is not present, the shot peening will cause the silver plate to blister and peel at the defective areas.

8. Shot peening as a means of porosity correction in castings.

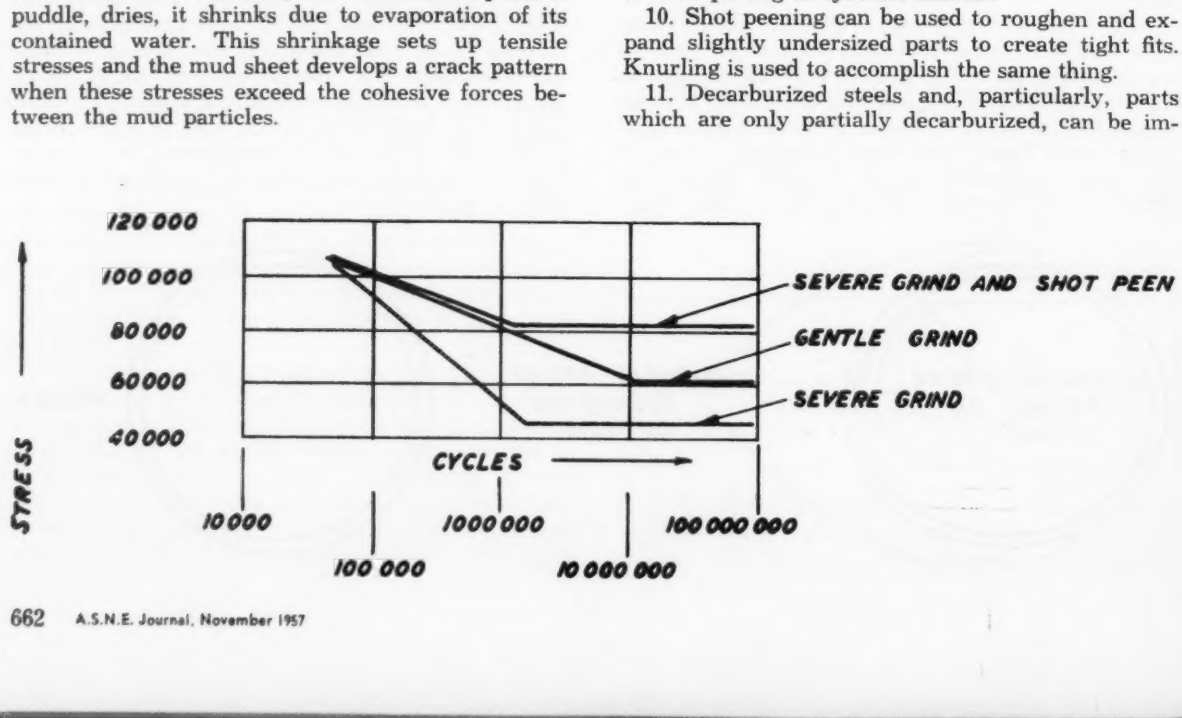
Small pores in castings can sometimes be sealed by the plastic flow of the surface metal due to shot peening. It is not effective for large pores.

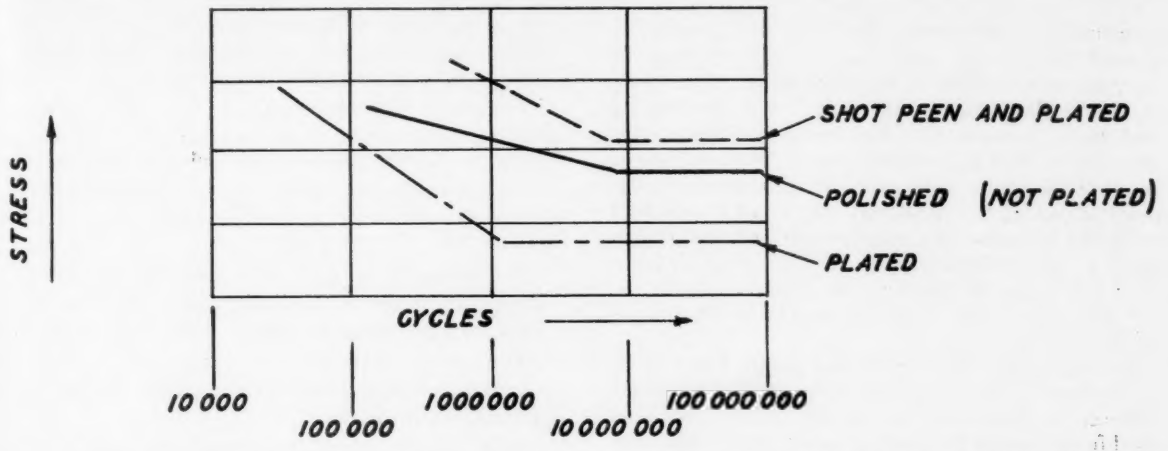
9. Shot peening to give an oil retentive lubricating surface.

This is a very valuable technique and has been largely overlooked by the engineering profession. One German automobile has cylinder barrels which have been shot peened and then chrome plated. The indentations caused by the shot peening are oil retentive. Due to the increase in fatigue properties, this process is probably superior to the porous chrome plating of cylinder barrels.

10. Shot peening can be used to roughen and expand slightly undersized parts to create tight fits. Knurling is used to accomplish the same thing.

11. Decarburized steels and, particularly, parts which are only partially decarburized, can be im-





proved by shot peening; however, shot peening will not improve a decarburized part to the point where it is as good as a properly heat treated part.

12. Ultrasonic activated parts, such as cutting tools, which are subject to extreme cycling (such a tool expands and contracts 27,000 times per second), can be greatly enhanced lifewise by shot peening. This is a case of fatigue property improvement.

13. Another case which nicely illustrates the improvement in fatigue life due to shot peening is its use on overload protection devices. A machine which was subject to jamming and breakage of integral parts due to overload, was given overload protection by machining a fillet in the drive shaft so as to cause the shaft to shear at the fillet when a jam occured. This fillet served the purpose intended but failed rapidly by fatigue. By shot peening the fillet, the fatigue failures were eliminated and the overload device functioned effectively.

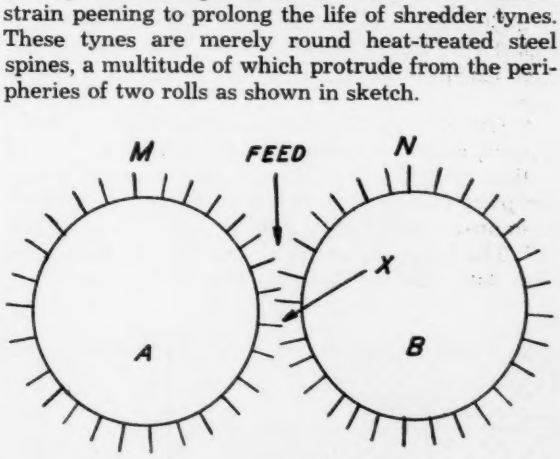
14. Deburring by shot peening.

Deburring can sometimes be effectively and economically accomplished by shot peening. A part which is to be carburized or hardened can, in some cases, be left undeburred and be hardened by shot peening. The peening blasts away the hardened burrs and the increase in fatigue strength resulting from the peening more than offsets any detrimental surface effects caused by the burrs being broken away.

15. Some parts are shot peened as a means of texturing the surface for esthetic purposes.

I would like to mention strain peening at this point. This has previously been referred to with respect to the hammer peening of carriage leaf springs on the convex side while subject to a bending load and tests show that it is particularly advantageous in the spring field for both coil and leaf types. If a coil spring, subject to compressive loading in service, is compressed to about 80% of the tensile strength in a jig and then shot peened, its resultant fatigue life can be increased some twenty fold over the life expectancy that would be achieved if it were shot peened to the same extent in the uncompressed state. The fatigue lives of an identical set of springs, one of which was unpeened, one normally peened and one strain peened would be of the order of magnitude of 1 to 10 to 200. It should be borne in mind that any flexed part is essentially a spring whether used for that purpose or not and that by flexing the part under a jig imposed load in the same direction that it would be flexed in service and then shot peening the convex (tension stressed) side, we are strain peening the part and its fatigue life will be greatly enhanced.

A specific example in mind would be the use of strain peening to prolong the life of shredder tynes. These tynes are merely round heat-treated steel spines, a multitude of which protrude from the peripheries of two rolls as shown in sketch.



In this device, one roll (B) rotates at a greater speed than the other (A) and such materials as linoleum scrap are fed through the tynes for shredding so that the material can be reprocessed. Due to the difference in speed of the rolls and the resistance of the scrap linoleum against the tynes, the shredder tynes of roll B are flexed (beam loaded) in a clockwise direction (Up-at the point of contact X) while those of roll A are flexed down (also in a clockwise direction). If then, with reference to the point X, the tynes of roll B are flexed up and peened on the underside and those of roll A are flexed down and peened on the top side, we will have ap-

propriately strain peened the tynes and greatly improved the life of a part which would otherwise be very prone to failure. In actual practice, these tynes would be flex loaded and peened in a holding jig and then inserted into the holding holes of the shredder rolls. Care would have to be exercised to see that the tynes were properly positioned. At the point M on roll A, the peened side of the tyne would be to the left since this tyne would be flexed downward at the shredding point X. The tynes at point N of roll B should also have the peened side to the left since (at point X) the tyne will be flexed upward.

An alternative and far simpler method would be to shot peen the tynes overall or cold work their surfaces in a tumbling barrel. This would not give the life advantage of strain peening but would give a valid life increase and, at the same time, permit the tynes to be assembled at random. There are many instances where one factor (the greater life increase due to strain peening) will outweigh the other (simplicity of accomplishment and ease of assembly) and vice versa.

For informative purposes, we will mention some specific article applications of shot peening.

1. Hamilton Standard uses shot peening on propeller hubs to increase the fatigue life.

2. In the aircraft industry, bolt heads which are subject to high loading and vibration are peened in the fillet between the head and the shank.

3. Starter rotors the teeth of which broke out at 45,000 rpm due to fatigue, were shot peened and gave excellent service at speeds in excess of 45,000 rpm.

4. Other items on engines such as piston rods, tappets, shafts, rocker arms, etc. were shot peened in their critical areas (fillets, angles or points where the parts change from heavy to thin cross section) to improve their fatigue life.

5. The following graph shows the life results on some latch springs given various treatments.

6. In the oil well industry, such items as drill pipe, sucker rods, mandrels, swivel pins, cutter bodies, etc. are peened to give extended life.

7. Torsion bars—by shot peening and presetting, the life of torsion bars can be increased from about 30,000 to 250,000 cycles or an eightfold increase.

8. Gears, whether carburized, quenched and tempered or annealed, are shot peened to increase fatigue life.

One example is that of a case hardened gear, stressed to 80,000 psi in service, which had its cycle life increased from 200,000 to 30,000,000 cycles as a result of shot peening.

9. Marine propellers—shot peened to prevent cavitation and fatigue.

10. Airplane propellers—peened near hub end to increase life.

11. Propeller hubs—peened on cone seat bearing area to prevent fret corrosion cracking.

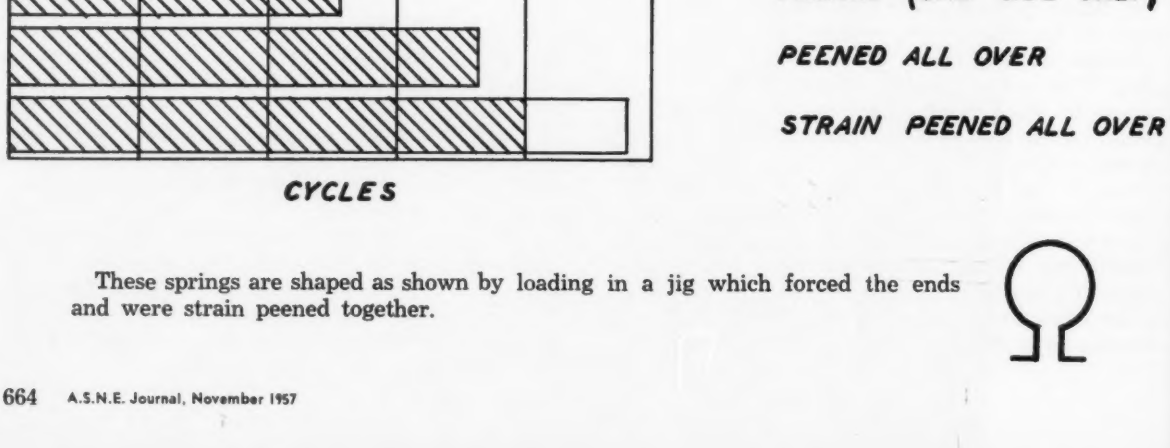
12. Exhaust pipes are peened to improve fatigue life and this gives effective improvement even though the part reaches a temperature of 850° F.

With respect to high temperatures, it has been demonstrated that by shot peening notched (notch serves as a stress riser) specimens of Nimonic 80 at .008A2 intensity a 30% improvement in fatigue life resulted even after tempering (heating) the shot peened parts for 50 hours at 1000° F. A high strength alloy steel shows a strength loss of only 1000 psi after shot peening and tempering for 100 hours at 700° F.

13. Link belt chain rollers gain an effective life increase by shot peening.

14. Pole line hardware such as eye bolts and turnbuckles can be improved by peening.

15. Brittle failure from low temperature can be avoided by shot peening.



These springs are shaped as shown by loading in a jig which forced the ends and were strain peened together.

ADDITIONAL NOTES ON SHOT PEENING WHICH ARE WORTH REMEMBERING

1. Except for the very smallest sizes of shot, air pressures over 50 psi should not be used.

2. In most cases, the increase in fatigue life it not particularly influenced by shot size; however, some recent tests have shown that bigger shot may cut fatigue strength. It is therefore advisable to use the smallest shot that will give the correct arc height and coverage at the saturation point.

3. Care should be taken not to overpeen metals (such as copper, self hardening manganese steels and some types of stainless steels) which work harden rapidly.

4. Surface finish prior to shot peening has a good deal of influence on fatigue life. Shot peening actually tends to roughen fine finishes; however, this roughening effect is not detrimental due to the increased fatigue strength which results.

5. The new SAE numbering system for shot sizes is based on high and low limit screening; however, the number following the S is actually the nominal size of the shot in ten thousandths. For example, the largest size shot (S-1320) has an approximate nominal size of .1320″ diameter. S-330 has .033″ diameter and the smallest size shot (S-70) has a nominal size of .007″ diameter.

6. Improved fatigue life of steel parts increases as the hardness of the parts increase and shot peening becomes less effective as the mass of the part increases.

7. Shot peening is less effective on straight push-pull types of cycling than for other cycle induced stresses; however, it oftentimes renders life improvement even in this case.

Don't be afraid of shot peening. Considerable material has been covered in this treatise to demonstrate the how and why of shot peening to controlled specifications; however, there is another side of the story and it concerns the shot peening of parts by operator judgment only. In spite of the fact that there is a correct (scientific) way to establish the proper arc height and peening conditions to give optimum fatigue life improvement to a specific part, the fact still remains that this method is exceedingly time consuming and expensive. It is seldom justified except in the case where the cost can be prorated over a very large production volume or where the part is so prone to failure that it is absolutely necessary to establish the optimum conditions for fatigue life improvement.

It can honestly be said that most shot peening specifications are based, not on experimental results, but on the basis of a conservative guess by a person with some background knowledge in this field. The percentage of improvement in the fatigue life of cycled parts is so considerable, and the number of such cases where it works effectively is so favorable, that one is justified in assuming that a cycled part will be benefited if it is peened under the following conditions: 1. air pressures used are below 50 psi except for the very smallest shot, 2. coverage is fairly complete as judged by eye, 3. a small (S70 to S170) to medium (S-230 to S-460) size shot is used and 4. care is taken that the critical areas being peened are fairly uniformly and completely covered. Though these conditions will seldom give maximum improvement to the part, they will almost invariably improve the part.

Suppose for example that a trip hammer on a machine was constantly failing. This would probably be due to fatigue and shot peening the area where failures occured could very probably remedy the failures or, at least, greatly decrease them. The peening procedure would be to establish the critical areas on the part and, with a nozzle pressure of 40-50 psi, direct a blast of S-110 to S-230 steel shot against the critical areas until the coverage seemed complete by visual examination. If the critical areas were not readily apparent, the part would be shot peened overall except for areas which are machined to a fit tolerance. Such machined areas would be stopped off by plugging holes (as threads) or bores with rubber (or even wood) plugs and outer surfaces would be covered with rubber adhesive tape (scotch or friction tape can be used). There is little doubt but that the part would be improved and that this is a valid operating procedure. If there were a considerable production of these parts, they would be fixtured and peened under controlled conditions to give the customer the assurance of uniformity of quality in his product to which he is entitled.

By way of substantiating this method of approach, let us examine some of the basic ideas behind it.

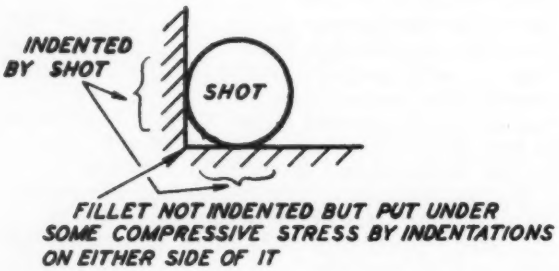
1. There is nothing mysterious as to why shot peening is so beneficial in obviating fatigue failures. It creates surface compressive stresses in the part and there is a wealth of evidence to show that fatigue failures do not occur where such stresses exist. Even plate glass is made immeasurably stronger when processed so as to create surface compressive stresses although (due to the brittle nature of glass) this is done by thermal upsetting. Other nonmetallic materials (as rubber and plastics) can accrue lengthened service life by inducing such beneficial surface stresses in them.

2. We have already mentioned the ancient use of hammer peening and it is well to note that the shot size in this instance was the size of the ball on the hammer. Another interesting anecdote along this line was told by a professor of metallurgy at the University of California to the effect that an early Wright diesel airplane engine owned by an Alaskan bush pilot developed a crack in a critical area and this crack gradually propagated until it became a matter of extreme concern to the pilot. Rather than be put out of operation while waiting for a new part, the pilot took a chance and heavily ball peened the metal at the end of the crack. This engine was used for over five years in the cracked and peened state and was taken out of service for general debility and not because of the crack. This is a case where a crack (stress raiser) propagating by fatigue could not penetrate through a compressively stressed metal area.

3. Even sandblasted metal parts show improvement in fatigue life over uncleaned parts. Sand is a pretty sharp edged type of shot.

4. In the automotive industry, shot blasting is used for cleaning a good many parts and this blasting improves them fatiguewise. Shot blasting can be considered as shot peening in its most uncontrolled form.

5. With respect to coverage, it has been shown that a coverage of as little as 30% will give 80% of the effectiveness in increased fatigue life that can be achieved by full coverage and it has been demonstrated that the unimpinged areas between the shot indentations are in a state of compressive stress though not to the same degree as they would be with full coverage. It can be seen from this that a very sharp groove or fillet into which a shot particle will not quite penetrate will, nonetheless, be improved fatiguewise by the indentations set up at either side of it as shown:



In spite of the fact that improvement will result in this case, the fillet at least should be gone over with a blast of finer shot to give added improvement.

6. If one were to examine strain peening theoretically and without knowing the excellent end results it achieves, we would be very apt to condemn such a method on the basis that it would probably result in over-peening.

It can be seen from the foregoing that shot peening by operator judgment is a valid, though not an optimum, method of approach providing, of course, that the operator has reasonable skill and experience.

UNINVESTIGATED VARIABLES IN SHOT PEENING

An example of a variable which, to my knowledge, has not been investigated would be the shot peening of a part at different temperatures. There is no good reason to assume that a part receives optimum benefits by being shot peened at room temperature as is now universally done. It is entirely probable that a different improvement, or lack of it, would result if a part were peened while hot (as immediately on removal from a tempering furnace) or cold (as immediately on removal from a deep freeze box). This might well be an insignificant variable and any improvement resulting from such an operation might be too inconsequential to be worth the added effort; however, until valid experiments have been carried out in this direction no one can assume that the results would not be significant and worthwhile. I have made some very cursory experiments along this line by the simple expedient of taking an Almen "A" strip, block and holding fixture (the strip being already attached to the block and fixture) to a desired temperature and then shot peening it immediately to a definite room temperature arc height. That is, the entire assembly was taken to the desired experimental temperature, shot peened for a definite time and intensity (.015A2 at room temperature) and immediately removed and measured for arc height while still hot. 25°F increments between —80°F and +400°F were checked with plotted results of arc height against temperature showing an increase of .001A2 arc height for about every 100°F increase in temperature. Arc heights varied from .013A2 at the lowest temperature to .019A2 at the highest temperature. After the strips had returned to room temperature the arc heights remained within .0005A2 of the original (hot or cold) measurement with the distinction that those measured hot increased slightly but very definitely when re-measured at room temperature while those measured cold decreased slightly but very definitely in arc height when remeasured at room temperature.

This demonstrates that the temperature of the part being peened is a bona fide variable; however, a great deal of research will be necessary to determine whether or not such variations will greatly improve a part so treated.

Another interesting experiment is that done by Richard Harvey wherein he marquenched parts and then shot peened them while they were still at the marquench temperature and, hence, still in the austenitic state. The resulting benefits were substantial though the specific applications of the process have to be much more thoroughly investigated.

This is a fairly lengthly treatise; however, I feel that it will give the reader an insight into the process of shot peening which cannot be attained except by experience and considerable reading of other literature. In concluding, I would like to mention that there are a great many aspects and uses of this process which have not yet been developed. If a part is failing, it won't hurt to try it.

"THE MARINE ENGINEER & NAVAL ARCHITECT"

DUTCH SHIPYARD'S GEAR FACTORY

ACKNOWLEDGEMENT

This is a staff article published in the April and June 1957 issues of "The Marine Engineer and Naval Architect."

THE pattern of world shipbuilding has altered radically since the beginning of this decade. The number of steamships in the over 15,000 tons gross class actually under construction has risen from 38 at the beginning of 1950 to 102 at the end of last year while the present order book is many times that figure. Twelve million deadweight tons of tankers, most of them in the larger sizes, were ordered in the last six months of 1956. No longer is the large passenger steamship the only class of vessel to be fitted with high-power geared turbines, for it was as long ago as 1954 that we described the first merchant vessel to have 20,000 s.h.p. on a single screw.

EARLY GEARS LIGHTLY STRESSED

The turbine machinery of the 1930/50 era suffered very little gearing trouble. This was largely owing to the moderate ratings adopted, but present practice is tending to ask much more of the gear-maker in order that his product may match the more advanced lightweight high-speed turbines. Space and weight are often at a premium and compact, light gear units are now in demand. Gears of this type can only be achieved by the closest attention to design, materials and accuracy.

Many of our readers will be familiar with the marine engine works where temperature-controlled, air-conditioned "hobbing cells" are employed for gear cutting. In these the machine tool and the work-piece are maintained at constant temperature in order to avoid errors due to expansion and contraction. Heavy insulated doors or a sliding roof enable the work-pieces to be loaded on to the compartment. This article describes the logical development of this principle, not a large hobbing cell but a temperature-controlled marine gearing factory.

The Royal de Schelde Engineering Co. of Flushing has one of the most respected names in marine engineering. It has been supplying gears for its own and other makers' turbines since 1917 when the first Reinecke hobbing machine was installed in the main machine shop. Gears have been supplied for a large number of famous naval and merchant vessels including the *Nieuw Amsterdam, Isaac Sweers* and the four-engined passenger motorship *William Ruys*. To date some 170 sets aggregating over 1½ m. transmitted h.p. have been delivered.

Post-war trends led the company to review their gear-cutting facilities in the light of recent advances in the art and the probable demand for increased production, not only from their own shipyard, but from other shipbuilders in Holland and elsewhere.

In 1950 the decision was taken to build an entirely new factory in which all the gear manufacturing plant would be concentrated. The site chosen was to the rear of the handsome main office block, quite removed from the main machine shops or other source of ground-borne vibration. The past year has shown how far-sighted the company has been.

FOUNDATIONS

In order to obtain a building as free from vibration as possible it was necessary to make exceptionally deep excavations and to drive closely spaced piles for the foundations of the new building and machines. As originally laid out, it consisted of a single bay 150 ft. long with a span of 75 ft. and a height of 46 ft.

The factory is a steel-framed brick-walled structure well lit on both sides by laminated insulating glass windows so as to avoid the thermal effects of bright sunshine or intense cold. Fluorescent light

fittings supply even illumination during the hours of darkness. The lighting load is some 45 kW. and a photo-electric cell is arranged on the roof in order to ensure that the lights are dowsed in the morning when daylight is sufficiently powerful.

The entire space is maintained at a temperature of 20° C by means of a large heating/cooling plant. This consists of an oil-fired heating boiler and a Schelde ammonia refrigerating plant installed in a room at the rear of the building. Air is drawn from the space into longitudinal trunks arranged at the base of the side walls and is then passed through a thermostatically-controlled heater or cooler-radiator (according to ambient conditions), before being returned to the factory through a pair of longitudinal ducts above crane track level. The large vertical sliding doors at the front and rear are flanked by fan heaters to prevent a drop in temperature during the brief periods when these door are open. A 50-ton travelling cane (now to be strengthened for 70-ton loads) spans the sidewalls and can reach any spot on the floor. Administrative offices, an inspection record room, cloakrooms and washplaces are arranged at the north end of the factory.

This building was completed in 1952 and in it were installed the Reinecke hobbing machine which was removed from the engine works, a Maag gear wheel generator, Maag gear wheel grinder and Maag pinion grinder together with a Trebel dynamic balancing machine and a meshing frøme. These machines will be described in closer detail later.

Shortly after the building was completed the increased demand for large gears began to make itself felt and two new gear hobbing machines were ordered from the well-known makers, Schiess of Dusseldorf. To accommodate these new machines the shop was extended south by some 63 ft. and this work was completed last May.

CLIMATE MAINTAINED THROUGHOUT

A new principle is also employed at Flushing for the final stages of manufacture, for not only are the rotating elements machined in a temperature-controlled atmosphere but they are checked individually and together in a meshing frame and finally assembled in the gear case in the same temperature-controlled dust-free conditions. The De Schelde engineers consider that it is pointless to go to all the trouble of high-precision gear cutting and then to assemble the components in a drafty open shop where appreciable dimensional variations due to expansion are likely to take place from day to day and even from hour to hour.

The gear case casting or fabrication is received from the main engine works after the machining of the faces and boring of the bearing seats has been performed. All subsequent work on the gears—assembly, testing at light load, preservation, dehumidification and sealing—is carried out in the factory, before it is dispatched from the shop. It goes out with a set of comprehensive instructions concerning subsequent preservation and routine inspection, should it not immediately be installed in the vessel for which it is intended.

The two Schiess hobbers are machines of the highest precision capable of producing gears to an accuracy inside 25 per cent of the closest British standard 1807 Class A1 limits. The larger one can maintain this accuracy when cutting main gear wheel of up to 17 ft. 6 in. diameter and the smaller one up to 7 ft. 6 in. The machines are of similar design and construction and therefore only the larger one will be described in detail.

LARGE SCHIESS HOBBER

This machine (Figure 1) took eight months to erect and rests on a foundation block 22 ft. deep, weighing 12 times its own weight of 125 tons. It consists of three basic elements, the work-table, the bed and the column which carries the hob saddle. The work-table rotates in the stationary base which is bolted to the end of the bed upon which the column, with its vertically moving saddle, can travel. The main gear box is at the end of the bed remote from the table and the drive is from multiple variable-speed motors. The table, 15 ft. in diameter, seats upon an oil film in a deep vee-groove circular track. This groove has sides with different slopes, one with a slight inclination to take the weight of the table and the other at a steep angle to ensure precise location. The work-piece may weigh as much as 100 tons, and is supported independently of the table by a bearing which is fitted in the pit beneath the machine and carried on a steelyard compound lever arrangement. This is, of course, capable of adjustable loading and enables the table to be relieved of the work load which could be a source of inaccuracy.

The table is driven from a common drive shaft by two indexing worms which can be adjusted to eliminate backlash. For setting-up, there is a high-speed drive and a horizontal hydraulic jack which can be hinged from a bracket at the end of the base is a useful accessory for moving the work slightly on the table when performing this operation. Accurate setting-up is achieved by means of a Solex air-gap micrometer which is capable of showing a movement of one micron over a quarter-inch of scale reading. A further check is made before the final cut is taken.

The hob saddle is supported and counterbalanced from the column by braided steel cables which ensure that the load of the hob saddle is not carried on the feed screw. The slide and swivel-head assembly is designed so that the distance from the center of the hob spindle to the guide is as small as possible, thus reducing side thrust due to the cutting load.

HOB-SPINDLE DRIVE

The hob spindle is driven through what might be described as a dual-tandem or locked-train of worms thus relieving the bearings of side loading and automatically compensating for backlash. A single gear on the drive shaft meshes with two skew gears which are coupled to a pair of worms arranged on

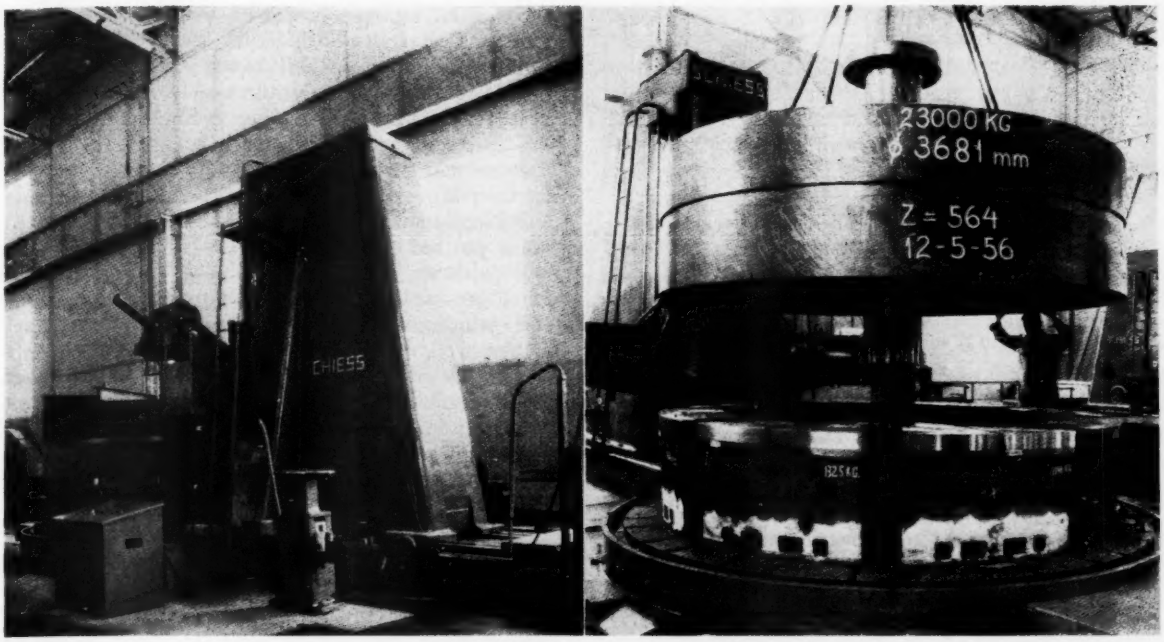


Figure 1. Two views of the larger machine. On the left can be seen one of the control desks and balancing gear for the table load. On the right is shown the first main gear wheel blank being loaded on the table.

either side of the worm wheel which actually drives the hob spindle. This arrangement can be seen in Figure 2. The drive is thus taken through small comparatively high-speed components.

The change gears for the indexing mechanism are carried within two enclosed panels at the after end of the machine. Those actually to the rear are for setting the number of teeth and those at the side are for the helix angle. These have quite independent lubrication and oil filtering systems. All the change speed wheels have ground tooth profiles and a separate detachable box is provided for use when gears with a prime number of teeth are required. These are sometimes used when it is particularly required not to have a recurring frequency between pinion and gear. As an example, those for the Shell 18,000 tons d.w. tankers have 263 teeth.

The various variable speed motors are supplied with power through an A.E.G. 440-volt, 24 kW. motor-generator set. The motor for the table drive has a speed range of 680 to 2,250 r.p.m. The maximum cutting speed for roughing is 16 m. per minute and for finishing is 12 m. per minute. Stepless speed changes of the hob are possible over the range 0 to 100 r.p.m. It is intended to increase these cutting speeds considerably as more experience is gained but the above figures refer to carbon steel of 60 to 70 kg. per sq. in. tensile strength for main wheels and 80 to 90 for pinions. A small point, but one which is indicative of close attention to detail, was a cover over the ahead or astern spindle starting button on the control desk. This ensures that the machine cannot be started in the wrong direction.

INDEPENDENT ACCEPTANCE TESTS

Erection of this machine was completed in mid-March, 1956, when an intensive series of tests and examinations was carried out. The first gear cut by the machine was completed in July. So anxious were De Schelde to establish high standards of accuracy that they called in Prof. Dr.-Ing. Felix Eisele of the Technische Hochschule Munich, to carry out an independent examination. Abstracts of his report are given below:—

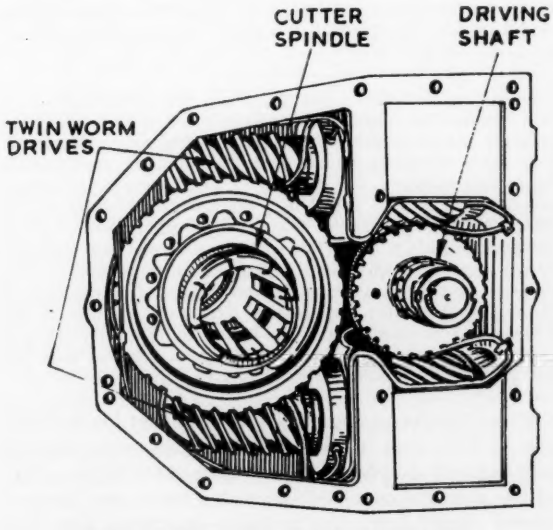


Figure 2. Twin worm drive for hob spindle.

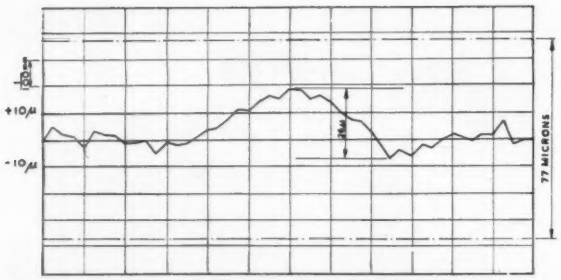


Figure 3. Cumulative pitch error measured over 47 groups of 12 teeth showing maximum error of 26 microns as against B.S. 1807 tolerance of 77 microns.

At the "De Schelde" Shipbuilding and Engineering Works, Flushing, Holland, two gear hobbing machines were installed by Schiess. A. G., the official acceptance of which was entrusted to the Institute for Tool Machines of the Technical University of Munchen.

Since then, two gear wheels (263 teeth) and three pinions (two H.P. pinions with 40 teeth, and one L.P. pinion with 64 teeth) have been completed on hobbing machine RF30. The adjacent and cumulative pitch error of wheels and pinions were determined and the random measurements indicated in B.S. 1498/1954 were carried out to establish the accuracy and quality of the products.

In addition the undulation and surfaces were checked of the hobbed teeth flanks. The results prove in general that the wheels and pinions hobbed with machine RF30 are of extraordinary quality. As requested by "De Schelde" we state hereunder the particulars of these findings. The overall error of the two wheels amounts to 26–30 per cent of the permissible values for gear wheels of Class A according to B.S. 1807. The adjacent pitch errors were measured in the manner prescribed in B.S. 1498, in different planes of the wheels. The maximum values measured were 28 per cent of those laid down in B.S. 1807 for gear wheels of Class A. The undulation of the teeth flanks (measured with the undulation recorder) was well within the required value for testwheels.

The measurements carried out, under our supervision, on the pinions gave the following results:—

The overall error amounted to 30 per cent of the allowable error for pinions of Class A, according to B.S. 1807. The adjacent pitch error showed maximum values of 30 per cent of the allowed value in B.S. 1807 for pinions Class A. The undulation of the flanks had values between 50 and 70 per cent of those laid down in B.S. 1807 for Class A pinions.

Following my letter dated 22nd June, 1956 (VA/31/3), I am now completing test measurements with a trial wheel on hobbing machine RF40/60 (12 ft. 3 in. dia. with 564 teeth). I am able to report to you that exceptionally good results have been achieved. The cumulative pitch error of this wheel amounted to only 25 per cent of the values permitted in B.S. 1807 for Class A wheels. The adjacent pitch errors which were measured on both rims in two places showed values of 32 per cent of the B.S. 1807 figures for Class A wheels. Undulation test measurements showed figures of 50 per cent of those laid down for test wheels. The tooth contact of the wheels and pinions hobbed on Machine RF40/60 were also registered. Here again results were found such as have not been achieved elsewhere without shaving.

From the foregoing it will be apparent De Schelde are no believers in post-finishing processes such as lapping and shaving. They consider that by exercise of the greatest care high-accuracy gears can be produced direct from the hobbing machine. The first ship to have gears cut on the new machines was the K.P.M. tanker *Munttoren* a vessel built by C. van der Giessen and fitted with Werkspoor turbines. She is generally of Shell 18,000 tons d.w. general-purpose design, a number of which have been built by private owners for charter to Shell. The trials of this ship were entirely satisfactory and if noise level measurement is any criterion, De Schelde can rest on their laurels until the manufacturers of turbines and auxiliary machinery take action to reduce the noise emitted by their products.

Here, also, large reduction gears are cut by the Maag generating system with subsequent hardening and grinding of the tooth profiles. Where space and/or weight are at a premium such gears do confer considerable advantages, for the use of hardened teeth enables much higher linear loading to be employed with consequent reduction in gear-case length. These gears are necessarily of single helical type due to the limitations imposed by the mechanics of subsequent grinding process. In the case of gears of the highest power, the so-called locked train or dual tandem type is to be recommended.

GEAR PROFILE GENERATING

When the Royal de Schelde Co. built their new factory they installed an outfit of Maag machines. Among these machines is an SU300/500 gear shaper which works according to the generating system and can cut straight and helical teeth in cylindrical gear blanks by means of a rack-shaped cutter. The workpiece rolls along the tool as if it were already a gear wheel, and the teeth are produced during this generating process. The cutter carries out a reciprocating up and downward motion parallel to the tooth flanks and cuts normally during the downward stroke, while it is withdrawn from the workpiece during the return stroke. The generating motion, taking place during each return stroke, is performed by the work table, which carries the gear to be cut. It is composed of a straight and a revolving motion of the work table, controlled by change wheels. If gear blank and tool had the same number of teeth, the gear would be cut during one uninterrupted

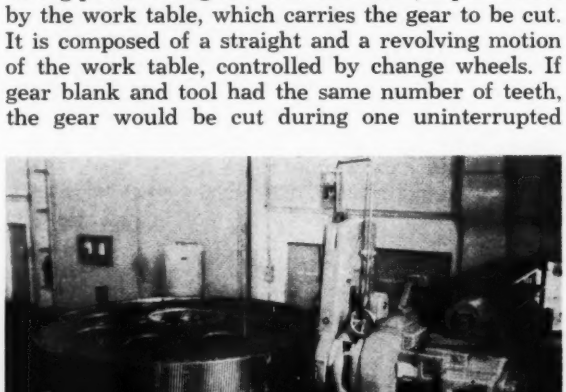


Figure 4. The large MAAG gear generating machine which can cut wheels up to 16 ft. 6 in. dia.

revolution of the work table, but as the cutter is of limited length, the blank is periodically brought back to its initial position relative to the cutter. During the return motion, the work table runs backward parallel to the tool, which remains at rest in its highest position. As the workpiece does not revolve during this operation but moves in a straight line only, a dividing motion is carried out simultaneously, i.e. the gear blank is advanced one or several tooth spaces relative to the cutter. The return motion is followed by a short backward and forward rolling of the work table, which serves for taking up the play in the driving mechanism for the generating and dividing motions.

After the tooth height or cutting depth, i.e. the correct distance between the axis of the table and the top edges of the cutter teeth, has been set, the gear blank is fed laterally into the teeth of the cutter in the direction of the straight table motion. The automatic generating and feed motions are now engaged, and continue until the gear is finished. The machine then stops automatically. Lateral feed of the cutter into the gear blank is only necessary when roughing. When finishing, the cutter is fed radially to the proper depth.

HEAT TREATMENT

A case-hardening Ni-Cr alloy steel is generally used for pinions and small gear wheels up to 3 ft. diameter. These arrive from the steel works as rough-turned annealed forgings. They are subsequently hardened and tempered in order to obtain the correct grain structure for the subsequent operations. After turning to size the tooth profiles are formed on the gear shaper, leaving about 0.2 mm. on each tooth flank.

In the case of larger wheels, a heat-treated Ni-Cr 140 kg/mm^2 alloy steel is employed. After gear cutting the pinions and smaller wheels are taken to the heat treatment shop which contains Holland's largest gas carburizing plant. This process is carried out in two stages using Wild-Barfield equipment. Firstly, a true carburizing of the surface with a constant supply of fresh town gas and, secondly, a diffusion period without gas flow. The results of this process are characterized by a very smooth transition from the carburized layer into the core material. After carbon diffusion, the charge is placed in another pit furnace for cooling in an atmosphere of nitrogen during which time the material is annealed. A suitably dimensioned test-piece is treated together with the blank for checking the thickness of the carburized layer and the case structure is checked by metallography of the workpiece itself.

Those faces which have to remain soft after quenching are then machined to remove the carburized layer. The next stage is a process known as Martempering which consists of careful heating and quenching in a salt bath at 200° C. The pinion and wheel are then cooled in still air. The subsequent quenching yields a very fine hard layer with minimum distortion and freedom from cracks. The blanks are finally tempered in an air-circulated furnace. Throughout all these processes the temperatures are automatically controlled and permanent records are available from the recorder traces. The surface hardness of the tooth flanks is measured by means of a Vickers testing machine.

TOOTH GRINDING

After hardening, the pinions and wheels are returned to the gear factory for finishing. There are two Maag gear grinding machines, one a HSS90P pinion grinder, capable of handling pinions with minimum and maximum diameters ranging from 180 to 900 mm., and the other is a large gear wheel grinder HSS360 with minimum and maximum working diameters of 1,100 and 3,800 mm.

The Maag gear grinding machines also work according to the generating method. The involute tooth flanks are produced geometrically correct by rolling the teeth to be ground along two saucer-shaped grinding wheels. The edges of the rotating grinding wheels represent the flanks of a hypothetical rack. Any wear of the grinding wheels is automatically compensated by a device readjusting the grinding wheels. The generating motion is obtained by accurately adjustable pitch blocks and pitch block bands. The edge of each grinding wheel touches the tooth flank at two points when the grinding wheels are set at 15 deg., and at one point when set at 0 deg. The small contact surface between grinding wheel and workpiece prevents any undue heating and, as grinding is performed dry, no grinding cracks occur.

Besides the generating motion, an axial feed motion is imparted to the workpiece, so that the grinding wheels touch the tooth flanks to be ground over the whole tooth width. After grinding two flanks, the feed motion is automatically stopped and dividing takes place. Thereupon the feed motion is started again. This process is repeated until all teeth are rough-ground or finish-ground, whereupon feed and generating motions are automatically stopped.

In the case of larger wheels having separate high tensile 140 kg/cm^2 wheel rims, these are hardened and tempered at the steel works before delivery. After machining the inside surfaces these are shrunk or bolted to the centers as required. The teeth are rough cut in the Maag gear generator which is the only machine suitable for working high tensile steel, leaving a 0.15 to 0.2 mm. grinding allowance prior to the final process which takes place on the large Maag wheel grinder. These machines incorporate the latest development which automatically provides tip and root relief.

Instruments for use in conjunction with the Maag machines include a cutter sharpening machine, pitch measuring equipment, a center distance checker and a helix angle checking device.

The pinion and gear are set up in a meshing frame and the contact marking is measured by means of special paints developed for this purpose. High-speed pinions and wheels are dynamically balanced

and the large slow-running wheels are statically balanced on parallel bars.

Assembly and final boring of the bearing seats take place in the same air-conditioned factory so that there can be no disparity due to temperature differences. The closest attention is given to the exclusion of dirt and extraneous matter. After assembly of the gear case the oil systems are thoroughly flushed by means of a special pump, heater and filters. Fine gauze strainers are fitted at all inlet points to the gear case and these are inspected at close intervals. During this flushing period the temperature and pressure are maintained at high values in order to ensure a satisfactory speed for flushing. This period ends only when all the filters have been shown to be quite clean. The first tests of the assembled gear are then carried out. These are run at light load and about half-speed, the rotating parts being driven by a motor flexibly connected to one of the pinion shafts. During this period the bearing of the teeth is examined and the journals are bedded down. Alignment measurements are taken at various points on the casing and these are subsequently checked when the gearing is erected with the turbines in the shop and later when installed on board.

NOISE AND VIBRATION TESTS

Noise and vibration measurements are carried out on the test bed and/or during sea trials. In this way the proportion of total engine room noise contributable to the gearing can be ascertained. A continuous check of bearing temperatures is made throughout all these tests and the gear teeth are inspected at frequent intervals.

The de Schelde Co. has laid down instructions for the preservation of gearing pending final installation and flushing the systems prior to sea trials. The gearing is dispatched from the factory with all rotating parts thoroughly coated with high viscosity oil. All openings are sealed and small sacks of hygroscopic material are secured within the case. These should be regularly inspected, for a change of color indicates an increase of humidity and possible ingress of moisture. The gear case should be kept sealed (except for routine inspection) until the last moment before fitting the turbine couplings. Daily inspection should thereafter be carried out and the pinions and wheels re-oiled should they become dry.

FITTING-OUT

With the completion of the engine installation the main lubricating oil system must be cleaned and flushed. At this stage it is important that all inlets to the gearing should be blanked off and the system thoroughly circulated up to the connecting points for the gear lubrication manifold. All pipe systems must be flushed without exception, and the pipes should be rapped sharply with a hammer to dislodge any scale. During this period regular inspection of the filters and gauzes is necessary, and the flushing continued until no dirt is found in any of the filters. Only then may the fine gauze filters be fitted to the inlet manifolds of the gearing system and flushing resumed. When it is established that these fine filters are clean they may be removed.

The bold policy adopted by the Royal de Schelde Co. in laying out so much capital at a time when the return was by no means certain has been amply justified, for the reduction gear order book is heavily committed for a number of years ahead. The fact that certain European turbine-builders have placed orders at Flushing for gears which are, physically, within their own manufacturing capacity is a measure of the very high standards of accuracy which are maintained.

TABLE I—*Capacities of Machines in De Schelde Gear Factory*

SCHIESS GEAR WHEEL HOBBER	
Max./min. wheel diameters	6,000/1,500 mm.
Max. wheel width	2,200 mm.
Max. module	24=1 D.P.
Max. helix angle	45 deg.
Max. weight of work-piece	100,000 kg.
SCHIESS WHEEL AND PINION HOBBER	
Max./min. wheel diameters	2,500/150 mm.
Max. wheel width	1,700 mm.
Max. module	24=1 D.P.
Max. helix angle	45 deg.
Max. weight of work-piece	25,000 kg.
REINECKE GEAR HOBBER	
Max./min. wheel diameter	4,000/200 mm.
Max. wheel width	2,200 mm.
Max. module	20=1.25 D.P.
Max. helix angle	45 deg.
MAAG GEAR SHAPER SH-300/500	
Max./min. p.c.d. of work-piece	5,000/150 mm.
Max. width of wheel at zero helix angle	500 mm.
Max./min. module	25=D.P.1/3=D.P. 8.5
Max./min. number of teeth	400/10
Max. helix angle	30 deg.
Max. weight of work-piece	7,000 kg.
MAAG PINION GRINDER HSS-90 P.	
Max./min. pinion diameter	900/180 mm. (Dep. on press.-angle and method)
Max. width of pinion at zero helix angle	800 mm.
Max./min. module	15=1.7 D.P./2=12 D.P.
Max. helix angle	30 deg.
Max./min. number of teeth	200/20
Max. length of work-piece	2,100 mm.
Max. diameter of pinion shafts	300 mm.
Max. weight of work-piece	2,000 kg.
MAAG GEAR WHEEL GRINDER HSS-360	
Max./min. wheel diameter	3,800/1,100 mm.
Max. width of wheel at zero helix angle	1,000 mm.
Max./min. module	20=1.3 D.P./3.5=7.5 D.P.
Max. helix angle	30 deg.
Max./min. number of teeth	600/100
Diameter of machine table bore	600 mm.
Max. weight of work-piece	25,000 kg.

COMMANDER BERNARD M. KASSELL, U. S. NAVY

POST-WAR SOVIET RESEARCH IN THE CENTRAL ARCTIC

THE AUTHOR

enlisted in the Navy in 1931, and has served continuously since that time. He attended Cornell University and Maryland University, obtaining his B.S. degree in Military Science from the latter institute. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. This is his fifth article to appear in the JOURNAL. *He is currently statitoned in Port Lyautey, Morocco. The materials contained in this article have been taken from Russian language publications. The translations are the work of the author.*

CURRENT PUBLICITY in connection with the International Geophysical Year and the Antarctic expeditions, in which Soviet scientists are participating, tends to overshadow longtime research efforts of the Soviet Union closer to home—in the central Arctic waters which border the northern coastline of the U.S.S.R. This research has been, and is going on in an area estimated to cover some 4.9 million square kilometers of the total Arctic area of about 13 million square kilometers.

Whereas the Soviet Antarctic expeditionary forces have been supplied by units of the Soviet merchant marine (*Lena, Ob, Kooperatsiya*), counterpart activities in the Arctic have been, and are being supplied by airlift, as well as by routine shipping in season. Various types of transport aircraft have been used in the Arctic and valuable experience under adverse operating conditions has been gained. It is difficult to arrive at any other conclusion than that the experience thus gained has found its way into Soviet research and development programs for all types of aircraft which may see service under Arctic conditions.

Because of the proximity of the Arctic to Soviet continental supply bases, it has been relatively simple to establish both permanent and temporary camps on the ice in the central Arctic and supply them as needed by air or by sea. The usual tour for personnel assigned to Arctic stations has been one year, but, as will be seen, many of the personnel have returned for a second, and perhaps third, tour of duty. These people, both scientists and non-scientists, now form a hard core of experienced Arctic workers, trained to work under the adverse conditions encountered during Arctic winters and able to train others in the arduous tasks encountered in that area. Weather is no respecter of ideology, or anything else, and whether one reads about the experiences of Soviet polar workers in Russian, or the experiences of Nansen, Peary, or Byrd in English, the hardships of continual snow, wind, ice, in fact the struggles for survival all sound the same.

It is no idle Soviet boast that "scientific work accomplished on the drifting ice of the central Arctic, in its scope and depth, has no equal in the history of polar research." This work has been accomplished by the simple expedient of setting scientists, maintenance personnel and equipment down on ice floes for indefinite periods of time and then having these scientists make observations as the floes follow an uncontrolled drifting course through the Arctic regions. Each such expedition is made up of approximately twenty oceanographers, geophysicists, meteorologists, aerologists, radiomen, workman, etc. Specially designed equipment has been developed for use in making observations and is usually easily portable as well as capable of withstanding the rigorous climate encountered. The Arctic Institute, prime mover in development work, has designed, for example, a magnetic self-recorder (which registers the sun's radiations and the earth's magnetic field) which fits into a small chest, as compared with a "huge and clumsy" apparatus installed on *Bolshaya Zemlya* to accomplish the same purpose.

With temperatures in the neighborhood of -22 degrees F to -40 degrees F, staying alive is a prime consideration. Soviet scientists have developed new materials for housing, new types of housing, new heating methods, ways to store foods, and have designed clothing to protect the station personnel and the flyers who bring in the supplies. One type of house, for example, is a spherical "tent" of special design

which can, without reinforcement, withstand high winds and is portable. The tent can be put up in from 20 to 30 minutes and is heated by gas stoves fed with liquid gas.

Instruments and equipment are designed to support the men who make the observations. For these observations, whether made during point-to-point aerial flights, or from permanent or drifting ice stations, provide the information needed to make the Northern Sea Route the strategic passage it has become. In addition, these observations provide the raw meterological materials needed for Soviet Air Force planning over what is now established as the most direct route to the heart of the United States.

Curious, but perhaps understandable, is the report that, for the International Geophysical Year the Soviet Union, through the medium of the Main Administration of the Northern Sea Route of the Ministry for the Maritime Fleet, will construct special pavilions in the Arctic, pavilions in which scientific work will be carried out. The implications of the announcement become clear when the locations are plotted:

Franz Josef Land	81–00 N	55–00 E
Cape Shalaurov	73–10 N	143–35 E
Wrangel Island	71–00 N	180–00 E
Uyedineniye Island	77–30 N	82–30 E
Preobrazheniye Island	74–37 N	122–50 E

Automatic radio-meteorological stations were to begin to function in the central Arctic this spring. Planning called for the establishment of some fifteen such stations at various points in the area; stations which are supposed to, at set times, transmit data on atmospheric pressure, air temperature, and wind velocity and direction. The meteorologists would thus obtain data enabling them to compile more accurate charts of the weather in the area and, in turn, this would enable them to turn out better forecasts as more widespread data were obtained.

Air support to all stations such as these is provided by Polar Aviation, a unit of the Main Administration for the Northern Sea Route, the personnel of which are civilians with military titles. According to the Arctic Institute, Polar Aviation has, in the years it has manned, supplied, and evacuated polar stations, never had an accident. Whether or not this is an exaggeration, published for foreign consumption, is of little interest. The point is, work has been going on for many years and it has unquestionably been carried on because the Soviets have been able to obtain and train aviators capable of operating in support of that work.

The greater share of original scientific work, in its broadest aspects, has been done from drifting ice stations, set up in various sectors of the Arctic over the years for varying lengths of time. Polar drift stations have been named and numbered in sequence, commencing in 1937 with "Severnyiy Polyus-1" (North Pole-1).* To date seven such stations have been identified, not all of which have been operable at the same time.

NP-2 was established in April 1950 under the leadership of a geologist M. M. Somov, now Doctor of Geographic Sciences. Initially manned at 76-02 N, 166-30 W, to the north of Wrangel Island, the station was abandoned a year later at 81-45 N, 162-20 W. During its drift the station moved northward some 600 airline kilometers, but over its curiously devious route actually logged a distance of over 2,500 kilometers. The area traversed by the station, originally designated in Soviet records as an "area of comparative inaccessibility," thus became an explored area and observations made by the station evidently filled a gap in the records.

No further activity occurred until the spring of 1954 when two stations, NP-3 and NP-4, were established. NP-3 was set up under Candidate of Geographic Sciences A. F. Treshnikov at 86-00 N, 175-45 W. NP-4, under Candidate of Geographic Sciences Ye. I. Tolstikov, a famed Arctic aerologist, was established in April 1954 at 75-48 N, 178-25 W, 500 kilometers to the north of Wrangel Island. Both stations were designated as "permanent scientific-research observatories" in the central Arctic. They were to be evacuated only in the event of grave danger to the personnel or in the event that research dictated reestablishment in a more fruitful area. In addition to semi-permanent housing and installations, the stations were furnished with trucks and tractors, generators for lighting and power, and, for ice reconnaisance and temporary observations within a 100 to 150 kilometer radius from the station, helicopters of the MI-4 type. This latter innovation greatly extended the mobility of the scientists and contributed enormously to the materials they were able to gather.

In its first year of drift, NP-3 covered more than 2,000 kilometers and, at the beginning of 1955, had reached the 86th parallel. However, the station had drifted over into the Canadian sector of the Arctic. NP-4, meanwhile, had drifted north and west so that it, by the beginning of 1955 had reached the 80th parallel, at which point it maintained its northward drift. It was NP-4 which found itself, during the summer period, in the rather precarious position of being surrounded by open water, separated from its ice landing strip by some 20 kilometers. Had it not been for the assigned helicopter, communications and support would have been impossible. However, with the coming of cold weather, the field closed in and normalcy was regained. On 19 April 1955 the personnel of NP-3 were taken off the ice and the station, its position now well established in the Canadian sector, was abandoned. NP-4 continued to operate, but under new management. In the spring of 1955, at about the same time the NP-3 was abandoned, a new crew of scientists, led by Candidate of Geographic Sciences P. A. Gordeyenko, was sent out from the continent in relief. The original crew returned to Moscow to a series of fetes and honors. NP-4 has

* Hereafter referred to as "NP-"

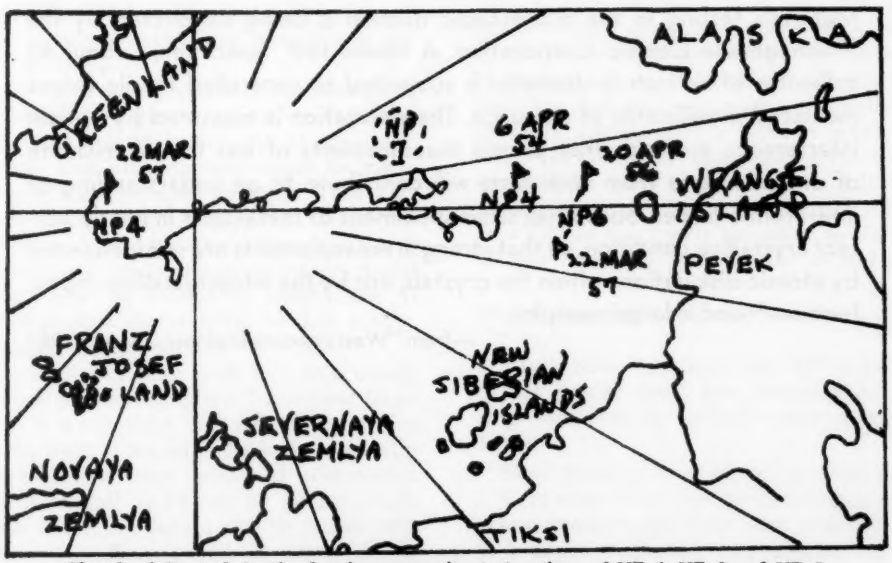
been manned by three different crews of polar workers. Currently under the leadership of A. G. Drelkin, who, as a Candidate of Geographic Sciences, had been a member of the original crew as assistant to Tolstikov, the station will shortly drift out of the central Arctic region and will be replaced by NP-7, the latest in the drift station series. In its three year existence, NP-4 has covered more than 7,000 kilometers of tortuous drift. On 5 July 1956 the station drifted to a point within 13 kilometers of the North Pole. Between September 1956 and March 1957 the drift described a huge loop as the ice passed along the 87th parallel westward. On 5 March 1957 the position was plotted as crossing the Greenwich meridian and, as finally reported, the station, on 25 March was at 86-48 N, 02-58 W, 350 kilometers from the North Pole, 300 kilometers from Greenland and 1,900 kilometers from its original manning point.

NP-5 was established on 20 April 1955 as a replacement for NP-3. Originally assigned to Candidate of Geographic Sciences N. A. Volkov, the station is presently under the direction of an oceanographer, A. L. Sokolov, who, with a relief crew took over the station early in 1956. NP-5 was established at 86-19 N, 86-00 E and has drifted in a general south and west direction which resulted in a position of 84-58 N, 73-14 E in September 1956. The area in which the station has drifted is one in which the weather, in a three month period from May to July 1956, was mostly fog and clouds. Nothing has been heard of this station since September 1956, and most recent indications are that the station may have been abandoned.

Latest addition to the active drifting stations is NP-6. On 19 April 1956 a plane set down a team of eight polar workers under the station leader, K. A. Syichev, 300 kilometers to the north of Wrangel Island. As distinguished from other stations, it was set up on a drifting ice island, the ice thickness of which was in excess of 11 meters and the expanse of which measured 13 by 11 kilometers. NP-6 has described a big loop in its aimless drift to the northwest and has logged 2,500 kilometer in progressing geographically a distance of 300 kilometers. Late in March 1957 the coordinates of the island were given as 75-25 N, 173-24 E, placing the station some 470 kilometers to the northwest of Wrangel Island. The island is drifting in a region of shallows where the water depths measure but 200 meters.

Arrangements for relief of NP-6's crew have advanced to the point where the new station chief has been named as a geophysicist, Candidate of Geographic Sciences, V. M. Driatskiy, who will head up for 1957-1958, a crew of 17 men including veterans of previous stays on the ice. Thus, the training program previously mentioned is beginning to yield its dividends in the form of experienced hands capable of taking over direction of a station, as well as men (and occasionally women) trained to perform the day-to-day operations of the stations.

Finally, there is NP-7, not yet formed, but which was in the formative stage late in March 1957. This station was to be the replacement for NP-4 and was to be formed in the eastern area of the central Arctic, to the north of Wrangel Island, but considerably closer to the pole than station NP-6. This is the same area in which NP-2, in 1951, completed its drift and suggests that Soviet scientists are now desirous of continuing work along the same general path followed by that station. The chief of the new station is to be an oceanographer, Candidate of Geographic Sciences V. A. Vedernikov who will head up the usual crew of 17 members, including what appears to be a nucleus of experienced polar workers. Since



Sketch of Central Arctic showing approximate locations of NP-4, NP-6 and NP-7, 22 March 57.

April has usually been the month in which station crews have been relieved, or the month in which new stations have been formed, it is possible that NP-7 is operational today.

Thus, we find that research goes on as usual, with at least two stations, NP-6 and either NP-4 or NP-7 manned, and possibly three, if NP-5 is still in service.

In the Soviet Union's view, one of the most important discoveries emerging from the work of the drifting stations is that of an underwater mountain range which now bears the name M. V. Lomonosov. The range stretches across the northern portion of the Arctic Ocean from the New Siberian Islands to Greenland, traversing the pole area and dividing the central portion of the ocean into two basins, completely isolated from each other. The range is over 1,800 kilometers in length and rises from the ocean floor some 2,500-3,000 meters, so that, in certain areas, water depths do not exceed more than 900 meters. In addition, it is said that vast underwater plateaus were charted and the bottom relief definitely established. It would appear that the theory, first enunciated by Fridtjof Nansen,* that the Arctic is a vast bowl with a comparatively level ocean floor at a depth of 5,000 meters, is erroneous.

The Soviets now firmly state that, as a result of observations made over all the seas in the Arctic, the interaction of cold and warm air masses over the central Arctic make up the weather for a considerable area of the northern hemisphere, so that study of weather conditions in the Arctic makes it possible to forecast weather on the continent.

Further, study of ice drift has led to a Soviet conclusion that the ice cover in the central Arctic is not a vast field of age-old ice. Ice is not the same all over the Arctic and, in fact appears to be made up of ice fields of various ages and thicknesses. It further appears well established in the Soviet view, that the general drift of polar ice is in the direction of east to west, towards the exit to the Greenland Sea. At the same time, along with this general drift into the eastern part of the ocean (adjoining Alaska and the Canadian archipelago) there is a slight drift, clockwise, called the anticyclonic ice drift.

Another scientific claim advanced as a result of observations is the existence of a "second magnetic pole" in the Canadian archipelago. The theory is that, over a vast distance stretching from the Taymyr Peninsula through the region of the North Pole to the Canadian Arctic, there is a narrow belt of extraordinary and very strong magnetism. Based on observations made, including those of the High Latitude Air Expeditions, the Soviets claim to have now drawn accurate magnetic charts of the Arctic which are needed by aviation in the high latitudes of the Arctic. The strategic implications of Arctic research thus are brought sharply into focus.

* 1861-1930. Norwegian scientist explorer, and statesman who, in FRAM, between 1893 and 1896, reached a position 85-57 N, after a total drift of 1,055 days between latitudes 83 and 86 north.

Materials testing in the microscopic domain is being conducted by the Westinghouse Electric Corporation. A tensile test "specimen," about 40 millionths of an inch in diameter is subjected to controlled tensile forces measured in millionths of an ounce. The elongation is measured by optical interference methods that permit measurements of less than a millionth of an inch. Data from such tests will contribute to an understanding of interatomic forces. Such small sized specimens of metal exist in nearly perfect crystalline condition, so that strength measurements are not influenced by atomic dislocations within the crystals, nor by the intracrystalline imperfections found in larger samples.

—from "Westinghouse Engineer," March 1957

R. BAKER

THE SHIP THAT WILL NOT CAPSIZE

THE AUTHOR

is a member of the Royal Corps of Naval Constructors and is at present serving as an Assistant Director of Naval Construction in the Admiralty. He received his early training in H.M. Dockyard, Chatham, and at the Royal Naval College, Greenwich. During the war he was largely responsible for the designs of landing craft and landing ships. From 1948–56 he was the Chief Constructor of the Royal Canadian Navy with the rank of Constructor Commodore. He is the author of a paper entitled "The Form and Stability of Ships" read to the Montreal Section of the Society of Naval Architects and Marine Engineers in 1954. He is a member of S.N.A.M.E. and also of the Institute of Naval Architects.

THE FEBRUARY 1957 edition of the JOURNAL included an article on the *Andrea Doria-Stockholm* disaster which drew attention to apparent deficiencies in the stability of the Italian ship even although she complied with all the requirements of the 1948 convention. The article went on to suggest that only by ballasting would really satisfactory arrangements ever be possible, and that some further tightening up of the Safety Rules would be required.

The purpose of this note is to call attention to another possible approach.

So long as there is any possibility of damage to ships by any means at all there is a liability that they will sink. More particularly in the case of passenger ships; when they sink arrangements must be made for the removal of the personnel on board. This is an impossible task if the ship disintegrates, sinks very rapidly, or capsizes. It is very likely that disintegration in some circumstances is non-preventable. Rapid sinking can, however, be limited by subdivision. It remains then to protect the stability so that a ship, even when sinking, will not capsize.

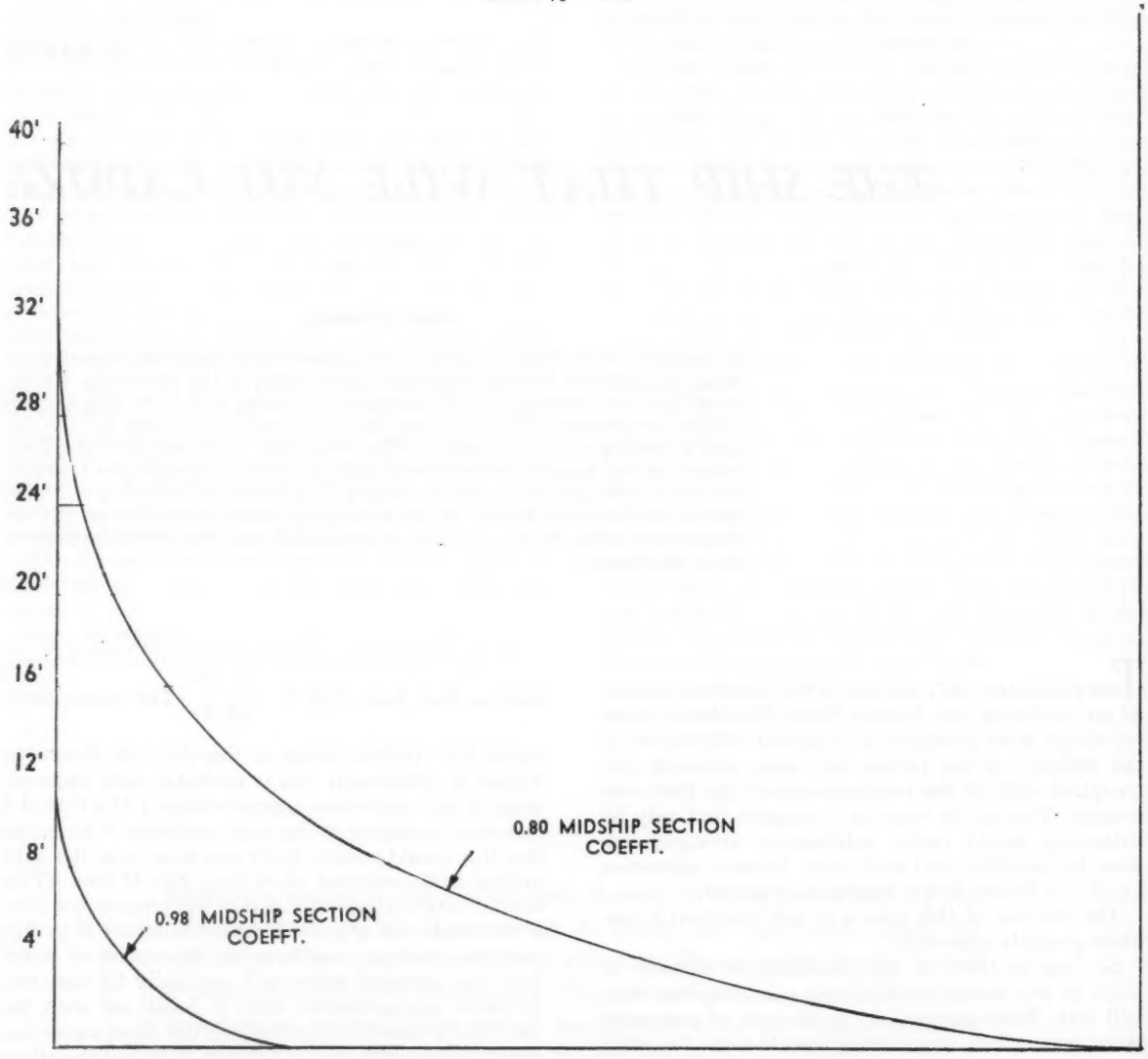
Theoretically it is very easy to do this. Practically it used to be done in the sailing era. In current large passenger ships it is not done. The only thing necessary is to fine the form of the ship. To deal specifically with the *Andrea Doria*, from published information she was 697 feet overall by 90 feet by 30 feet draft; 67¾ feet depth; Block coefficient of 0.58 (on the BP length); Prismatic coefficient 0.59. In other words, she was a fairly fine ship with a full midship section. Midship section coefficient was 0.98. Gen. E. de Vito implies that $Km = 0.55\ d + \frac{1}{13}\frac{B^2}{d}$. The metacentric curve for *Andrea Doria* is therefore as shown in Figure 2. (Although this is probably only approximate, it is a very close approximation.) If a GM of 4 feet were accepted in the load condition it might be that this would reduce to 2.0 feet at or near the light arrival draft assumed of 18 feet, KG 42 feet. (This is assumption also, but if it errs the error is not likely to vitiate the argument which follows.) If in this condition damage results in the admission of water then the admitted water will gradually fill one, two or more compartments until it levels off with the sea. If at a stage in this flooding the flood water has amounted to 2000 tons at a depth of 10 feet the effect of this water will be of a weight of 2000 tons acting at a virtual c.g. nearly the same as the ship "M" for 10 feet draft, viz: 68 feet, i.e. 26 feet above G. The virtual c.g. of the ship will rise by $\frac{26 \times 2000}{17{,}000\,(\text{say})}$, that is 3 feet. Simultaneously the "M" of the ship will fall 2 feet due to the 2 feet increase in draft and the ship will then be initially with a negative GM of 3 feet.

Slow flooding may be worse than rapid flooding.

Very close intact subdivision might, it is true, make it impossible to get 2,000 tons of water when flooded to a depth of 10 feet only and as the flooding proceeds the virtual c.g. of the added water falls. But, evidently, if instability occurs at any time during

Figure 1

Scale: 1/8" = 1'-0"



the flooding, the ship will take a list, and then although theoretically stable when fully flooded, she will in fact continue to list.

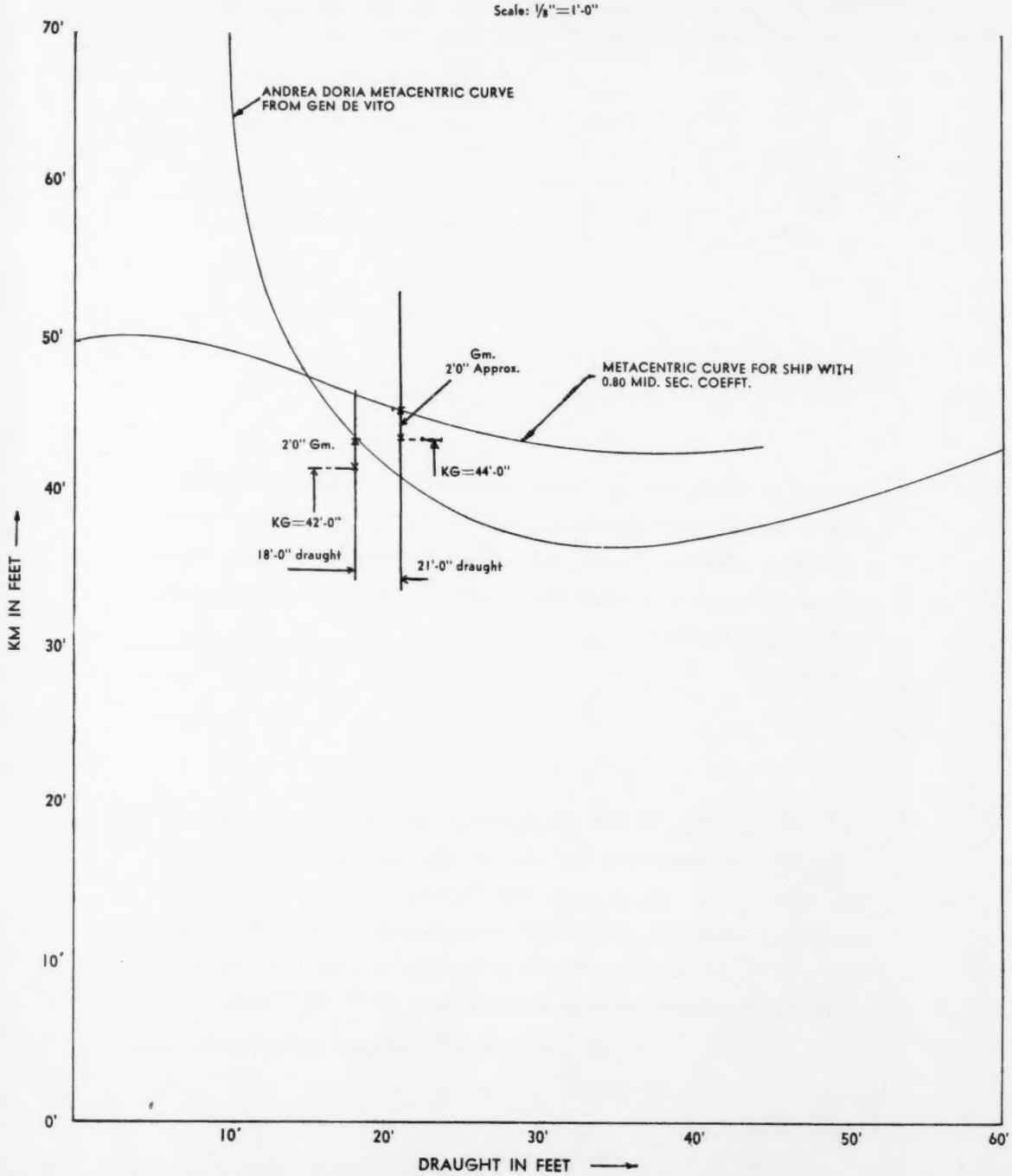
Flooding calculations ought therefore, by rule, to consider progressive flooding foot by foot and compartment by compartment until the ship sinks.

In a ship with a conventional tank top the effects will be worse as the virtual c.g. of the flood water will at all times be raised by the depth of the tank in all cases of side damage. The provision of a continuous inner bottom to above the deep water line does not help much for in all cases of flooding it will be pierced at least on one side of the ship. Longitudinal bulkheads will be worse as they will have their own listing effect.

Andrea Doria could however have been designed with a block coefficient of 0.50 and a prismatic of 0.62. The mid section coefficient would then be 0.80 and if the beam is increased to 96 feet, load draft would be 32.5 feet and the light draft 21 feet. Such an increased draft would imply increasing the depth to 71 feet and the light KG to 44 feet. Figure 1 shows the resulting midship section and Figure 2, the metacentric curve for a ship of these dimensions and characteristics. The light GM is still 2 feet. If 2,000 tons of water are admitted to a depth of 10 feet, the virtual c.g. is 49 feet, that is: only 5 feet above G. The rise of G is $\frac{5 \times 2000}{17{,}000}$, about 0.6 foot, and the fall of

Figure 2

Scale: 1/8"=1'-0"



M less than 0.1 foot and the ship has a positive GM of more than one foot.

Other depths of flood water and other weights can of course be considered and it may be that in the suggested re-design there is optimism as regards the height of the c.g., but it is certain that under all circumstances the ship with the full midship section will be in grave danger of taking a list, or of capsizing completely while the ship with the fine section can be arranged so that she will not capsize even if flooded from end to end (in which case she would of course almost certainly sink.) Subdivision is beneficial to an equal degree in both cases. The metacentric curve for the redesigned *Andrea Doria* considered here

falls only slightly as draft increases, but if a still finer form were adopted it would be possible to have a single skinned steel ship in which bilging would actually improve stability because the M curve would slope upwards.

Had *Andrea Doria* been designed therefore with a block coefficient of 0.50 and without longitudinal bulkheads, the only effect of the collision would have been to sink her two or three feet. Not only would it have been possible to use all the lifeboats—but their use would not have been necessary.

The advantages of fining the form seem therefore not only obvious, but overpowering.

Why then are full forms still the fashion?

Somehow or another when the world changed from wood built clippers to iron boxes someone went wrong. It is a long road back, but surely it is unreasonable not to try it, at least in ships whose only *raison d'etre* is to carry people in comfort and safety. It is possible to design ships of proportions not dissimilar to those of the Clippers with stability characteristics such that bilging improves their stability and from this point of view every passenger ship could, and therefore should, be a 10 compartment ship.

A 950 foot, 55,000 ton French flag passenger liner is planned for construction in the Panhoet Shipyards, St. Nazaire. The keel was laid in October. The ship is reported to have a designed service speed of 30 knots. Having a passenger capacity of about 2000, it will be air conditioned and equipped with anti-roll stabilizers.

—from "Maritime Reporter," June 1957

A 15,000 bhp engine built in Japan, the largest Marine diesel engine now in service, has passed ship trials. At full load, the engine delivers 15,107 brake horsepower with a mechanical efficiency of 89.5% and a specific fuel rate of 0.351 pound per brake horsepower-hour. The twelve-cylinder engine is an increased size version of the service proven Burmeister and Wain design 74-VTBF-160 type. It will power a 33,500 DWT tanker.

—from "Marine Engineering/Log," September 1957

NATHANIEL STEWART

CO-OPERATIVE EDUCATION: A SOUND INVESTMENT IN MANPOWER POTENTIAL IN NAVAL ENGINEERING

THE AUTHOR

serves as Staff Advisor for Special Programs in the Industrial Relations and Manpower Division of the Bureau of Ships, and is regarded as the founder and the "production manager" of the program described in this article. Readers of the JOURNAL *will recall his earlier article in the November 1951 issue of the* JOURNAL *on "Meeting a Manpower Crisis in Naval Engineering." The author is Professorial Lecturer in Engineering Administration at George Washington University, and he has lectured, published, and advised on manpower problems in engineering. Dr. Stewart's concern for and his efforts in behalf of manpower in naval engineering represent an important contribution to our profession.*

BACKGROUND AND DILEMMA

"SHIPS . . . SHIPS . . . SHIPS . . . AND MORE SHIPS" was the headline featured in *Newsweek* as it carried, at the opening of 1957, the journalistic account of the shipbuilding industry riding a crest of prosperity. A note of great enthusiasm ran throughout the entire account—with the increasing orders for the construction of tankers from Standard Oil Company of New Jersey and Gulf Oil Company, for luxury liners from Grace Line and United States Lines, for merchant vessels from many others in order to support the growing traffic to Europe in its surge of industrial recovery, for major construction of warships from the Navy Department, and the domestic and foreign shipyards booked to capacity and overflowing. And then—wham!—the closing observation that, on the negative side, there was almost certain to be a severe shortage of skilled manpower to accomplish that which needs to be done.

It is clear to many of us that the most critical shortage of skilled manpower will be encountered in the scarcity of professionally-educated and trained naval architects. The complexity of ship design and the modernization of ship structures, both military and commercial, is such that the recruitment and education of more naval architects must be our principal manpower target. As we move into an era of probable atomic-powered merchant ships as well as construction and conversion of many other types of ships to keep pace in this era, the need for naval architects will be even more acute.

For an industry which, historically, has had its cycles of feast and famine, and with them the shifts of professional and skilled manpower brought about by these economic fluctuations, it has surely had its share of negativism. But to have to face a feast period on a *negative* note, because of the lack of professional manpower such as naval architects and marine engineers and supportive draftsmen and technical aides, is even more severe. And, this is precisely where we are. We have witnessed a continuing small in-put of young men in the schools of naval architecture and a serious decline in the annual crop of graduates in this field to the point that we now face a manpower crisis. It is this scarcity of human talent in naval architecture, far more than a periodic non-availability of steel or the tax burden on corporate organizations or a labor strike, which will determine whether the shipbuilding industry can really "deliver" in this decade.

It cannot be known whether this rise in shipbuilding workload is but a temporary boom or whether it is a significant trend which may became an integral part of our economy for many years to come. One could speculate quite soundly that, if we should win the battle of ideas in our struggle with the Soviet Union for men's minds over the world and succeed in releasing more and more free nations to achieve a measure of their own self-sufficiency and economic enterprise and growth, there should emerge from this a vast potential in international ocean traffic. The military posture required for adequate defense should also assure a continuing good share of modern

warships, too. This boom could then well become integrated into our economy for the next decade or longer and, with it, continued ship design and construction and with commerce operating at a high level. But, this could seriously be jeopardized if we continue to experience the declining curve of naval architects.

THE MATHEMATICS OF THE MANPOWER SITUATION IN NAVAL ARCHITECTURE

There is lacking a comprehensive set of data of the manpower supply and demand in regard to naval architects. Nevertheless, it is possible to arrive at estimates within reasonable bounds. On the supply side, the annual compiliations of the U.S. Office of Education on engineering degrees conferred and some of the surveys of the National Science Foundation are of some value. Figures 1 and 2 disclose the supply of professionally educated naval architects over an appropriate period—gauged in terms of B.S. degrees conferred. The number is small and there is evidence of a declining curve. This is reflected both in the composite summary and in the data of each of the three institutions which offer a degree in naval architecture. (Note: The compilation does *not* include those who prepare for careers in naval architecture through courses at the University of California, Berkeley, the U.S. Naval Academy Stevens Institute of Technology, Virginia Polytechnic Institute or other institutions where there are

THE DECLINE IN THE ANNUAL NUMBER OF (B.S.) GRADUATES IN NAVAL ARCHITECTURE AND MARINE ENGINEERING
(TEN-YEAR PERIOD, 1947–1957)

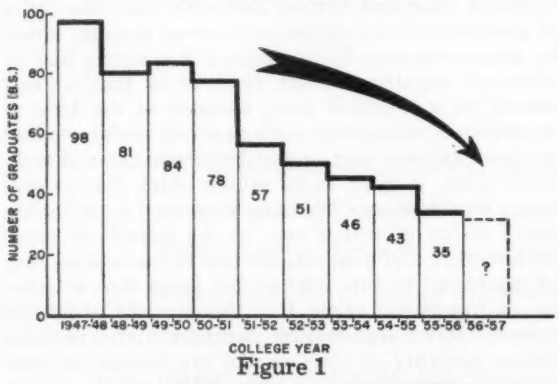


Figure 1

LOW AND DECLINING NUMBER OF GRADUATES (B.S.) IN NAVAL ARCHITECTURE AND MARINE ENGINEERING
(SHOWN BY MAJOR SCHOOLS)

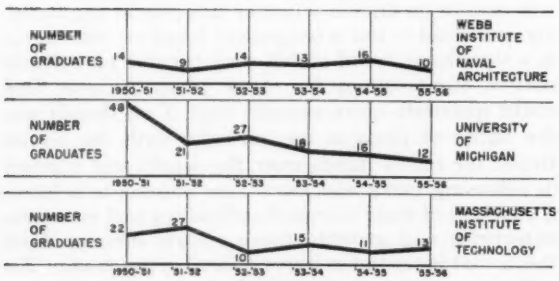

NUMBER OF GRADUATES
14 9 14 13 16 10
WEBB INSTITUTE OF NAVAL ARCHITECTURE
48 21 27 18 16 12
UNIVERSITY OF MICHIGAN
22 27 10 15 11 13
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
1950-'51 '51-'52 '52-'53 '53-'54 '54-'55 '55-'56

Figure 2

available electives or a major concentration in naval architecture but the B.S. degree in Naval Architecture is not offered.) In brief, the three principal institutions are turning out approximately forty (40) graduates a year in naval architecture and marine engineering. On the assumption that an additional ten (10) achieve preparation through courses in the non-degree institutions in this field, the total annual crop would reach fifty (50).

It is recognized that a number of employees can be of service as "home grown" naval architects and assigned to the less difficult work in theoretical design and to sub-professional responsibilities in a ship design center. While they have had no professional education in this field, or perhaps very little, they attain some competency through occasional after-work courses, on-the-job training, and other exposures. Among these are a number of technicians, draftsmen, and engineers whose basic preparation might have been in civil or structural engineering and who have been "converted" for the time being to be of service in the naval architect ranks.

On the demand side, again, there is lacking a set of comprehensive data regarding the aggregate need for naval architect personnel in government, business, industry and education at home, and for service abroad. Projected estimates for naval architects made by the naval shipyards and other field activities of the Bureau of Ships, for the five-year period 1957-1961, express the need for 350-375. To this is added the need indicated by the Bureau headquarters in Washington, D.C.—and the demand for naval architects on a Bureau-wide basis reaches a total of 410 440. As the major Federal agency employing naval architects in considerable number, the data of the Bureau of Ships offer some barometer of the need Modest needs for staffing naval architects exist in the Maritime Commission, Coast Guard, Military Sea Transportation Service, and some of the Army establishments concerned with river vessels, landing craft, and various amphibious craft. The manpower needs in the field of education—for instructorships and professorships, laboratory technical advisers, and others in the university's department of naval architecture and marine engineering—would appear to be quite limited. In any event, it would represent the smallest fraction of the total need. The estimated demand expressed for such personnel in private business and industry offers a problem because of the absence of any survey data. The data of the Department of Labor on this score are well out of date. However, informal interviews suggest that the aggregate need for the next five years would be 500 to 600. This would include ship design agents, ship construction firms, repair yards to a very minor extent, and others. It would cover, too, aeronautical firms which will find themselves unable to employ as many aeronautical engineers as are needed and may turn to naval architects for work on hull design and experimental tests—especially such firms as contract for constructing large aircraft which have capabili-

ties as sea-planes. Thus, the total demand for naval architects for the five-year period may be estimated at approximately 1,000.

The mathematics of the manpower situation in this field would indicate that we have a probable out-put (supply) of fifty graduates a year while the demand would approximate two hundred a year—the demand exceeding the supply by four times. The margin of demand would have to be increased as we take into consideration the rate of retirements, deaths, mobility to other engineering fields, and other developments. Personal replacements will be needed here over and beyond the supply-demand picture already indicated.

THE MAIN BARRIER TO MANPOWER POTENTIAL IN NAVAL ARCHITECTURE

What accounts for the very limited number of young men interested in naval architecture as a career? Answer: *the paucity of information.* From many experiences of recruiters on a nation-wide basis and from other sources it has been confirmed repeatedly and is strikingly clear that young people are quite in the dark as to naval architecture as a profession. They have access to little or no information as to what naval architecture is as a professional undertaking, what it offers in the way of career opportunities, what the naval architect does in his typical work-day, or how one prepares for competency in this field. Conferences with high school principals, teachers of science and mathematics, and high school counselors and advisers on vocations and careers revealed that they are uninformed in regard to naval architecture and its career opportunities. This is true, too, with respect to counselors in junior college programs. The net effect, then, is that parents and their promising youngsters, soon to graduate from high school, are also uninformed and have no exposure by which to consider naval architecture as a possible career. Indeed, this prevails even in communities in the seaport cities and other geographic areas close to the nautical influence, so to speak.

Other factors exist, to be sure, which affect the manpower potential: the very few available institutions with curricula in this field; the administrative and admissions policy which operates to some extent in limiting the enrollment of potential naval architecture students in the college; the discouraging word of elders who have witnessed the feast and famine in the employment of naval architects in the past; and other considerations. However, the hidden element and the main barrier to the manpower potential in naval architecture is the paucity of information and communication media for young people in their upper high school years in regard to the profession and its career opportunities. There is abundant information for them in regard to law, nursing, journalism, medicine, teaching, agriculture, public service, and many other fields. The professional societies and other agencies have also increased in volume and in attractiveness the literature and brochures in various engineering fields—chemical, electrical, civil, aeronautical, and mechanical engineering. Little is available for dissemination to serve the same purpose in bringing to the attention of young people an orientation to naval architecture as a career possibility. Unfamiliarity with the field and its opportunities is largely the reason for passing it up as a possible career field. Young people know the more classical and publicized fields and can often have the opportunity to see professional practitioners in action. This has not been the case in naval architecture, although there has been some beginning in naval shipyards in conducting guided tours for high school youth groups and explaining at least the principal function and work of the men engaged in ship design offices. More needs to be done to hurdle this barrier of "no knowledge of what it's all about."

CO-OPERATIVE EDUCATION IN NAVAL ENGINEERING

Bureau of Ships—Field Activities Co-op Program in Engineering and Science

With the foregoing as a backdrop the Bureau of Ships took the initiative in formulating and installing a major Bureau-wide program which was designed to (1) "break the ice" by making possible, for carefully selected young men, an unusual opportunity to combine college studies leading to full professional preparation in naval architecture with realistic and productive employment in this field; (2) enlarge the manpower potential in this field; and (3) publicize, to a much greater extent, naval architecture as a career. The new program and its special features was brought to the attention of high school educators, career counselors and vocational guidance directors, parents, Civil Service Commission offices in various regions over the United States, and to young people in their upper high school years. This was part of a larger program incorporating not only naval architecture but all branches of naval engineering and related sciences. The "Highlights" of the Bureau of Ships—Field Activities Co-op Program in Engineering and Science, Figure 3, outline the principal features of the program.

The response to the program in this initial year has been remarkable, as has been its general acceptance by engineering educators, government officials, and the public. Within the brief recruiting period of January through June in an effort to reach both the mid-year and the closing year high school graduates, more than 5,000 promising high school graduates applied for entry into the program. Considering the many other attractive scholarships available for these promising youngsters, it is quite significant that some 5,000 students on the east and west coasts have shown their interest in this Bureau of Ships—Field

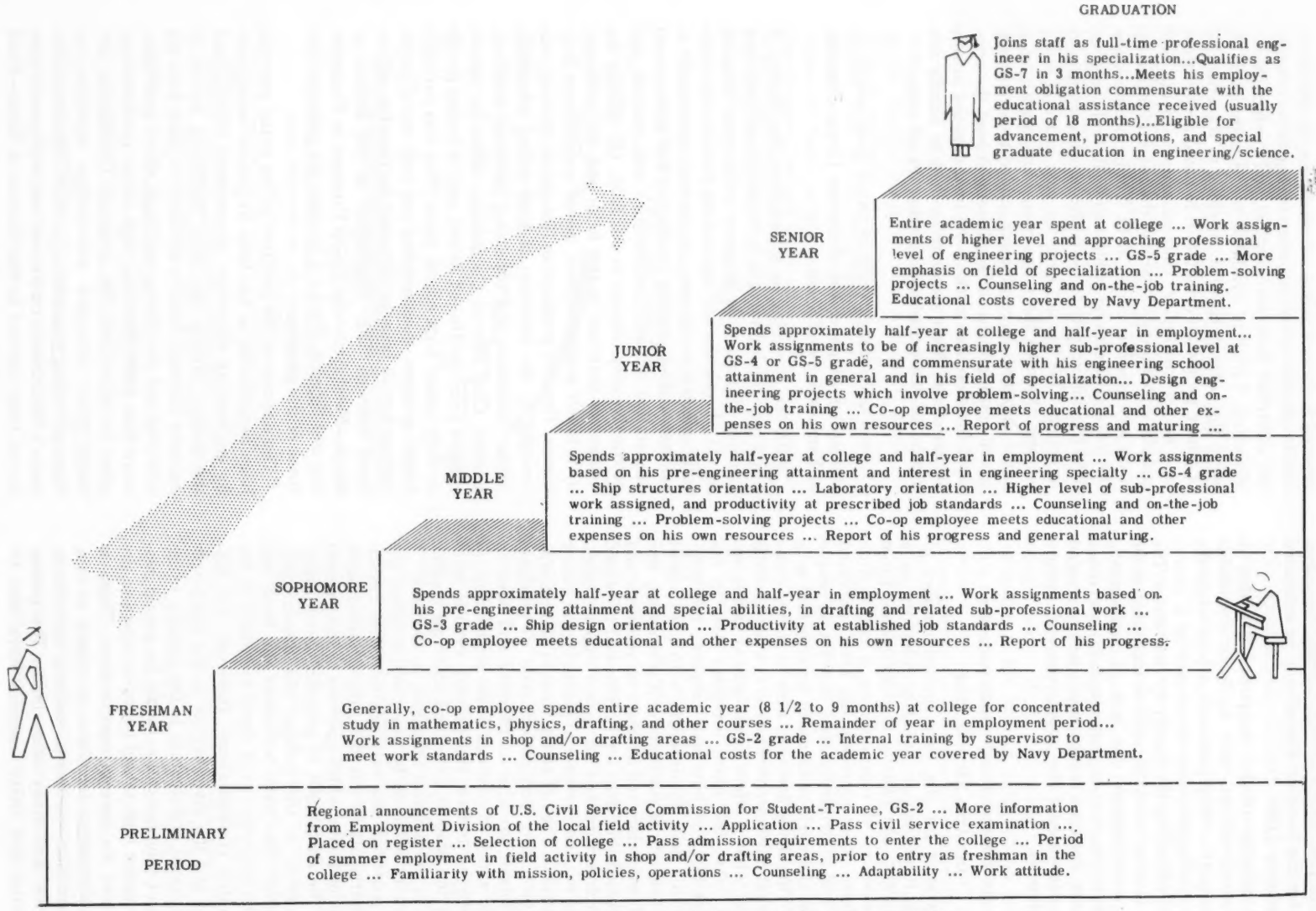

GRADUATION
Joins staff as full-time professional engineer in his specialization...Qualifies as GS-7 in 3 months...Meets his employment obligation commensurate with the educational assistance received (usually period of 18 months)...Eligible for advancement, promotions, and special graduate education in engineering/science.
SENIOR YEAR
Entire academic year spent at college ... Work assignments of higher level and approaching professional level of engineering projects ... GS-5 grade ... More emphasis on field of specialization ... Problem-solving projects ... Counseling and on-the-job training. Educational costs covered by Navy Department.
JUNIOR YEAR
Spends approximately half-year at college and half-year in employment... Work assignments to be of increasingly higher sub-professional level at GS-4 or GS-5 grade, and commensurate with his engineering school attainment in general and in his field of specialization... Design engineering projects which involve problem-solving... Counseling and on-the-job training ... Co-op employee meets educational and other expenses on his own resources ... Report of progress and maturing ...
MIDDLE YEAR
Spends approximately half-year at college and half-year in employment ... Work assignments based on his pre-engineering attainment and interest in engineering specialty ... GS-4 grade ... Ship structures orientation ... Laboratory orientation ... Higher level of sub-professional work assigned, and productivity at prescribed job standards ... Counseling and on-the-job training ... Problem-solving projects ... Co-op employee meets educational and other expenses on his own resources ... Report of his progress and general maturing.
SOPHOMORE YEAR
Spends approximately half-year at college and half-year in employment ... Work assignments based on his pre-engineering attainment and special abilities, in drafting and related sub-professional work ... GS-3 grade ... Ship design orientation ... Productivity at established job standards ... Counseling ... Co-op employee meets educational and other expenses on his own resources ... Report of his progress.
FRESHMAN YEAR
Generally, co-op employee spends entire academic year (8 1/2 to 9 months) at college for concentrated study in mathematics, physics, drafting, and other courses ... Remainder of year in employment period... Work assignments in shop and/or drafting areas ... GS-2 grade ... Internal training by supervisor to meet work standards ... Counseling ... Educational costs for the academic year covered by Navy Department.
PRELIMINARY PERIOD
Regional announcements of U.S. Civil Service Commission for Student-Trainee, GS-2 ... More information from Employment Division of the local field activity ... Application ... Pass civil service examination ... Placed on register ... Selection of college ... Pass admission requirements to enter the college ... Period of summer employment in field activity in shop and/or drafting areas, prior to entry as freshman in the college ... Familiarity with mission, policies, operations ... Counseling ... Adaptability ... Work attitude.

Figure 3. Highlights of the Bureau of Ships Co-Op Program in Engineering and Science

FIELDS OF SPECIALIZATION

ENGINEERING: Electrical, Mechanical, Aeronautical, Chemical, Electronic, Marine, Metallurgical, Air Conditioning and Ventilating, Nuclear, and other.

SCIENCE: Chemistry, Physics, Mathematics, Electronics Science, and other.

The pattern outlined is subject to modification to meet the academic calendar for the work-study system of the participating institution in the Bureau's co-op education program.

Activities Program with its opportunity to bridge theory and practice through this work-study program and its modest and optional educational assistance provisions. More than 2,300 of the applicants passed difficult examinations for the student-traineeships. Of this number the naval activities of the Bureau have, within their specially designated allocations for employing co-op student-trainees, been able to select finally some 500 for the program in this initial year. Approximately 400 are young men who have recently graduated from high school and approximately 100 are those who have had a year or so of college studies and who entered into the program as student-trainees with advanced standing. The co-op personnel finally selected, then, are those who ranked in the upper third or higher of their high school graduating class, passed the civil service examination (which approaches in difficulty the examination for entrance into the U.S. Naval Academy, Military Academy, or Air Academy), met the requirements for admission to the college in a period in which there are increasingly higher college entrance standards, and are highly motivated toward careers in engineering and science. In brief, the cream of the high school graduates have been entered into the Bureau of Ships—Field Activities Co-op Program in Engineering and Science.

In the five-year program of co-operative education the student-trainee expends half the year in pursuing his college studies at the institution and the other half in productive employment related to his professional interest and field of specialization. His earning power within this five-year period is equivalent to *one-half* of the annual salary levels shown below, since he is paid only for productive work during the employment periods:

First year	GS-2	$2,960
Second year	GS-3	$3,175
Third year	GS-4	$3,415
Fourth year	GS-4	$3,415-$3,670
Fifth year	GS-5	$3,670-$4,400
		upon graduation
Three months later	GS-7	$5,335

The job assignments of the student-trainee increase in technical difficulty and in responsibilities—from draftsman, technical aide, sub-professional assistant, to professional engineer.

It is noted from the Figure 3 that the program makes provision for educational assistance to cover the student-trainee's tuition and related educational costs to the extent of the 2/5 of the total educational costs of his college education and possibly up to one-half in certain cases. The two years in which the educational assistance is provided, generally, are those years (freshman and senior years) in which he is required by the co-op engineering college to spend the entire year at the college and consequently is unable to earn any money except through an occasional part-time job after school hours. The educational assistance, then, helps him in those years in which he experiences the largest financial burden—and for the other years in which he alternates between college studies and employment periods, at half-yearly or quarterly intervals, he is self-sufficient and expected to meet his own educational expenses.

THE CO-OP EDUCATION PROGRAM IN NAVAL ARCHITECTURE—MARINE ENGINEERING

Within this first year of the program co-op student-trainees have been enrolled in the University of Michigan, University of California, and the Virginia Polytechnic Institute. (The number of applicants was not as large as had been hoped, but at least sufficient to warrant the establishment of sound programs. The principal problem, as indicated earlier, is to generate and disseminate more information about naval architecture as a career and to reach high school teachers, counselors, parents, and the young people in their upper high school years.) In some instances they will begin at a local engineering college for their pre-engineering and liberal arts courses, and will then transfer to the upper division of the University of California for concentration in naval architecture and marine engineering where they will attain the degree with specialization in this field. Negotiations could not be completed in time with the Massachusetts Institute of Technology, although several years ago serious consideration was given by the Institute's officials to a co-op program in naval architecture-marine engineering similar to the plan which M.I.T. now has in electrical and aeronautical engineering. The nature of the program and the student body selected at Webb Institute of Naval Architecture for full-year studies and continual residence on the campus, for the most part, made it infeasible to enroll co-op student-trainees who in the Bureau's program would have to alternate between periods of employment and attendance at college.

The naval shipyards on the west coast, the Pearl Harbor Naval Shipyard, and possibly one of the laboratories will funnel their co-op trainees in naval architecture to the West Coast Program at the University of California. Largely through the cooperation of Professor H. A. Schade of the Department of Naval Architecture and Marine Engineering and Dean M. P. O'Brien of the School of Engineering, qualified co-op student-trainees will pursue their naval architecture-marine engineering studies there. It is probable that other naval activities on the west coast may also participate in the program at a later date, and it is hoped that private shipyards and design agents will also enroll similar trainees in the program. The Commander of the San Francisco Naval Shipyard, Captain C. E. Trescott, USN, serves as the principal liaison official in representing the Bureau of Ships in this west coast program and in the special program concerned with naval hydrodynamics in which personnel are pursuing advanced studies to the master and doctorate degrees. While the in-put will be modest at the outset, it is expected that the annual in-put will in time reach twenty-two (22) co-op student-trainees in this West Coast Program at the University of California.

The East Coast Program for co-op student-trainees in naval architecture has been established at the Virginia Polytechnic Institute. This institution has for a number of years enrolled personnel from the Portsmouth-Norfolk port area in its excellent co-op education program, has had continuing contact with the mission and the work of the Norfolk Naval Shipyard, the Charleston Naval Shipyard, and the David Taylor Model Basin, and enjoys a reputation as one of the leading engineering schools in the South. The groundwork for a program in naval architecture-marine engineering was established several years ago. A series of conferences between representatives of the Bureau of Ships and officials of the Virginia Polytechnic Institute in 1957 led to the establishment of the new program for co-op student-trainees in naval architecture-marine engineering. It is anticipated that approximately twenty (20) student-trainees will begin their studies in September. They are drawn from the New York Naval Shipyard, Philadelphia Naval Shipyard, Norfolk Naval Shipyard, Charleston Naval Shipyard, and the David Taylor Model Basin. Other east coast shipyards will probably enter additional co-op student-trainees in the program in the next academic year. It is hoped that in time there will be a total annual in-put of thirty (30) co-op student-trainees in naval architecture-marine engineering in the Virginia Polytechnic Institute program.

This was achieved through the joint effort of representatives of the Bureau of Ships and officials of the Virginia Polytechnic Institute. Dr. John W. Whittemore, Dean of the School of Engineering and Architecture, Professor J. B. Jones, Chairman of the Department of Mechanical Engineering, and Mr. John L. Cain, Director of the Co-operative Engineering Program were particularly instrumental in making the program possible at the institution. The institution is currently planning to engage the services of a full-time professor of naval architecture to develop, guide, and direct the new program. Bureau officials involved in setting the stage for this program and in assisting in the formulation of the curriculum and content of the new program were Mr. George A. Dankers (a graduate naval architect of the University of Michigan and deputy to the famed John Niedermair, Technical Director of the Preliminary Design Section), Mr. George F. Fonger (a graduate marine engineer of Webb Institute who has held highly responsible positions in this field), Mr. G. E Koenig, Head of the Training Branch for Field Activities, Mr. F. E. Raterman, the Director of the Industrial Relations and Manpower Division and Mr. Philip Meyerson, the Assistant Director of the Di-

TABLE I

CURRICULUM IN NAVAL ARCHITECTURE-MARINE ENGINEERING
Virginia Polytechnic Institute

First Year	
General Chemistry	Algebra
Western Civilization	Trigonometry
English Composition	Analytical Geometry
Introduction to Engineering	Military Science I
Engineering Drawing	
Second Year	
Statics	Mechanical Engineering Technology
Dynamics	Calculus
Principles of Economics	Differential Equations
English and American Literature	Physics
Public Speaking	Physics Laboratory
	Descriptive Geometry
*Third Year**	
Fluid Mechanics	Statics of Ship Design
Materials of Engineering	Mechanism
Mechanics of Materials	Heat Engineering
Introductory Surveying	Mechanical Engineering Laboratory
Industrial Electronics	Physical Metallurgy
Elements of Electrical Engineering	Dynamics of Ship Design
Ship Construction, Elementary	Hydraulic Machinery
(*Selections from above to be made, required and elective courses.)	
*Fourth Year**	
Intermediate Fluid Mechanics	Ship Structures Design
Engineering Economy	Instrumentation
Marine Engineering	Marine Engineering Design
Mechanical Vibrations	Heat Power Engineering
Machine Design	Internal Combustion Engines
Ship Hull Design	Mechanical Engineering Laboratory
	Naval Architecture I, II.
(*Selections from above to be made, required and elective courses.)	

vision and by the author. The administrative support of Rear Admiral S. N. Pyne, USN, Assistant Chief of the Bureau for Field Activities, and Captain A. M. Zollars, USN (Ret.) proved to be of great value in making the establishment of the program possible.

The institution has now in progress the assembling of many resources to strengthen the instructional and laboratory phases of the program. It is hoped that in time there will be a tow tank facility at the Institute or one available at a strategic location for the co-op student-trainees in this program. The degree offered will be B.S. in Mechanical Engineering (Naval Architecture and Marine Engineering), and will make possible a strong option in either naval architecture or marine engineering. The curriculum will probably take shape as shown in Table I, with the four conventional years spread over five years, of course, to allow for alternating periods of practical employment in the shipyards or laboratories and college studies in the co-op pattern.

The content in naval architecture will include: *Introduction to Practice* (ship types, nomenclature, general arrangement of ships, and the background and philosophy of naval shipbuilding); *Statistics of Naval Architecture* (areas, volumes, weights and moments, displacement, hydrostatic curves, cross curves, intact stability, damaged stability, subdivision, trim, with possible inclusion of regulations on freeboard and tonnage, launching, and grounding); *Hull Form Design* (hull dimensions and coefficients, sectional area curve, line plan, and appendages); *Dynamics of Naval Architecture* (resistance, propulsion, model testing, propeller design, ship motions, ship course control and directional stability—with possible inclusion of ship trials); *Ship Structures Design* (theory of structures in ship design; classification societies' rules, weight, shear, and bending moment, inertia of sections, hull girder strength, transverse and local strength, submarine structures, statically indeterminate structure, materials); *Introduction to Marine Machinery* (boilers and turbines, internal combustion engines, nuclear plants, fuels, auxiliary and deck machinery, shafting, steam reciprocating engines.) There will be required, too, a practical "thesis" project. The purpose of the project will be to determine the student's capacity to prepare, under supervision, a preliminary design when given certain specifications and characteristics. Marine engineering students will also participate in this project, with emphasis on the marine engineering aspects of the project.

The marine engineering curriculum will be covered in this pattern: *Marine Engineering I* (Elements of Propulsion Machinery—steam, diesel, gas turbine, nuclear; Auxiliary and deck machinery; Shafting; Marine fuels); *Marine Engineering II* (Basic considerations; Calculations and Performance—boilers, turbines, condensers, evaporators, heat exchange equipment; Steam conditions and cycles; Feed water treatment; Principles of combustion); *Marine Engineering* III (Basic considerations; Calculations and performance—reduction gears, pumps, compressors, fans, blowers; Auxiliary requirements; Heat balance; Transmission systems; Piping systems); *Marine Engineering IV* (Electrical equipment—generators, motors, control and distribution; Plant layout; and Design project).

The Substance of a Co-op Education Plan

Basically the cooperative plan is defined as an integration of classroom instruction and practical industrial experience in an organized program under which student-trainees alternate periods of attendance at college with periods of employment in industry, business, or government. The employment constitutes a regular continuing and essential element in the educational process in this integrated pattern, and in order to attain the college degree in a co-op education program the student-trainee must measure up to standards established both by the college and by the employer. If he falls short of meeting the standards either academically or as an on-the-job employee, he is subject to removal from the program. The plan requires that the student's employment be related to some phase of the branch or field of study in which he is engaged, and that it be diversified in order to afford a spread of experience. It requires further that his industrial work shall increase in difficulty and responsibility as he progresses through his college curriculum, and in general shall parallel as closely as possible his progress through the academic phases of his education.

The cooperative plan generally operates as follows:* A full-time job is obtained in an industrial concern or governmental agency, preferably near the college concerned. The job is shared by two students, one of whom works on the job while his partner or "alternate" attends college. At the end of a certain period (usually determined by the college calendar, semester or quarter) the two change places. Thus the job is kept continuously filled, and each student is enabled to spend approximately half his time in college. The length of the period of alteration varies in different institutions, as do the total amount of work experience periods required and the point at which it starts in the student's curriculum.

While the "two-man team" concept is generally observed in cooperative education programs, it is not universally followed and is not a fundamental principle of the system. In some institutions the cooperative program is so arranged that all co-op students go to work at one time, and all return to college at one time. Certain advantages are claimed for this type of program, but the majority of institutions still use the "two-man team" arrangement. Even in institutions which normally follow the practice of "pairing" students, adaptations are often made to provide only one co-op student for a given job, which can be handled in such a way as to permit him to return to college for the regular class periods in order to progress toward the degree. The concept of the co-op education program originated fifty years ago at the

* "Co-operative Education in the United States" (U.S. Office of Education Bulletin 1954, No. 11.)

University of Cincinnati under the leadership of Dean Herman Schneider of the College of Engineering. Some 35 engineering colleges now utilize the system either as the sole means of engineering education or along with the traditional four-year curriculum in engineering where students may enter either one of the two systems.

Over the years many industrial firms have capitalized upon this system and have regularly employed co-op personnel. Among these are General Motors, International Harvester Company, du Pont, General Electric, Westinghouse, American Telephone and Telegraph Company, and many others in the principal industries of this nation. The advantages to the student-trainee and to the employer may be summarized in this way: To the co-op student-trainee, the industrial experiences help him to participate intelligently in the shaping of his education in many ways, such as: (1) the practical test of his inclinations and adaptability help him to decide on a suitable type of work; (2) he is stimulated to make original investigations and to learn the practical applications of the theories he is studying in college; (3) his first-hand contacts with other employees and with problems of labor management increase his understanding of the human factors in industry; (4) industrial discipline helps him to form good work habits and to acquire a feeling of self-reliance and a sense of responsibility; and (5) he has an opportunity for partial or perhaps total self-support, and can command a better salary or opportunity upon graduation than can the regular student who has not had any industrial experience.

To the employer participating in the program by employing the co-op student-trainee, there are these advantages: (1) carefully selected employees are trained in company organization and procedures while securing a technical education, without the expense to the firm of maintaining a training school for such personnel—and, which it could not maintain since the student hopes to receive an academic degree in the field; (2) experience shows that many of these co-op student-trainees remain with the employing firm after graduation, and that they are very well qualified to step into responsible technical positions immediately upon graduation; and, (3) the exchange of ideas among students, coordinators, and supervisors leads naturally to the university becoming interested in the problems of the industry or employer, and ultimately establishing a closer link not only in training manpower but also in research and other areas.

It is a proven system, one which has turned out many men now in important professional and executive positions in engineering and science, and has measured up to the expectations of the student-trainees and the employers. Only recently in the semicentennial celebration of the cooperative education system some of the nation's foremost leaders, including Charles Kettering, urged that the system be extended and adopted more widely as a means of helping the nation meet its vital manpower problem in finding qualified people for work in engineering and science.

Other Areas of Naval Engineering in the Co-op Program

Within the total program, of course, the largest number of the more than 500 student-trainees selected are well distributed over other fields of naval engineering and related sciences. They are undertaking work-study programs in these fields in the same pattern as has been described. The student-trainees are pursuing studies toward degrees in mechanical, electrical, electronic, civil, air conditioning and ventilating, chemical, and other branches of engineering —and will have as their work portion of the five-year program corresponding job assignments in these fields in the naval shipyards. Other student-trainees are pursuing studies in the sciences, with concentration in chemistry, physics, mathematics, electronic science, metallurgy, and other fields as their specializations. They will be entered into a series of job assignments, progressively more difficult and approaching professional levels over the five-year period, in their chosen fields in the naval laboratories of the Bureau of Ships.

The Bureau of Ships—Field Activities Co-op Program in Engineering and Science now involves relationships with some forty (40) colleges throughout the nation. Most of the arrangements have been completed but several are pending. These include the recognized co-op engineering colleges as the hard core of our relationships in this program. They include, too, other colleges of the non co-op type but which have been able to develop special administrative arrangements by which the student-trainees in this program will be able to alternate between periods of college studies and employment in the naval activity in a five-year program leading to the degree. Among the participating colleges are Stanford University, Pratt Institute, Fenn College, University of California, California Institute of Technology, University of Michigan, University of Hawaii, University of Detroit, University of Pennsylvania, Northeastern University, Georgia Institute of Technology, and many others.

SUMMARY

The co-op education way, as a path by which promising youth can move toward careers in naval engineering, shows considerable promise in countering the difficult manpower recruitment situation in this field. In the field of naval architecture alone, it appears that under this plan the Bureau-Field Activities program may result in the in-put of 175-200 well-selected young men within the next five-year period for study toward degrees in naval architecture-marine engineering. Assuming that they have been so well selected, as has been indicated earlier in this paper, and that most or all could progress to the completion of the course of studies and attainment of the degree, this number in the Bureau's co-op program alone would yield ultimately the equivalent of

more than four graduating classes at the present national yield. In other words, if the several institutions with accredited programs in naval architecture yield an aggregate of some 40 to 50 graduates a year as is now the case, the co-op student-trainee in-put of 175-200 in the Bureau's program would in five years yield a number equivalent to more than four graduating classes throughout the nation.

This may be tempered, of course, by any unforseen developments such as economy measures curtailing the number of government employees, any change in the ratios of student-trainees to the total personnel of an organization, or other factors. It is hoped, however, that the seriousness of the manpower picture and the evidence of a declining in-put and meager out-put within the past decade, as shown in Figure 1, will support the view that this program should continue at a reasonable pace and volume.

There are some hidden assumptions here, to be sure—the assumptions that the student-trainees will "stick with the program," that their work assignments and daily supervision on the job will be sufficiently stimulating to sustain their interest in the field of naval architecture, that they will make the grade academically and will show progress in their work assignments, and that upon completion of the brief period of required military service they will return to the profession of naval architecture. This, to be sure, is the large task ahead. There will be required sound counseling, good human relations, and effective administration of the program to translate these assumptions into fact. It will call for individual coaching and encouragement, if we are to make the most of their exposure to the problems and professional approaches in naval architecture. Planning Officers, Design Superintendents, and Head Engineers will have to provide leadership for the supervisors who are at the branch, section, and unit levels in the organization.

As industrial organizations have over the past fifty years capitalized on the co-op education plan and have had a high rate of retention of these men as permanent employees when they have graduated, so there is this same potential for the naval shipyards, design agents, and others. But to capitalize upon it we must fulfill our end of this partnership with the engineering colleges and with the student-trainees and, of course, to administer the program soundly and to make improvements at every possible point in the years ahead. There is good reason to believe that co-op education represents a sound investment in manpower potential in naval architecture and in other branches of naval engineering.

In his last major address before retirement as president of the American Society of Mechanical Engineers, Dr. William F. Ryan called for vigorous steps to organize the engineering profession. As an essential first step, he scored the need for a comprehensive, detailed survey of the profession, similar to one conducted in the medical profession about fifty years ago which is credited to leading the profession to the status which it now enjoys. "Perhaps when we can find out who is an engineer and what he does, and when we undertake to let him do it, we will find that the shortage of engineers is not so great as we have feared," Dr. Ryan noted. He further stated that, while he agreed that American engineering education was the best in the world, he thought engineering schools might successfully pay more attention to professional concepts to help solve professional problems.

—from ASME Press Release, 23 September 1957

"THE SHIPBUILDER & MARINE ENGINE-BUILDER"

WELDED ALUMINUM SHIP STRUCTURES

ACKNOWLEDGEMENT

This article was published in the June 1957 edition of "The Shipbuilder and Marine Engine-Builder." It consists of an abstract of a paper read before The Southern Joint Branch of The Institution of Naval Architects and The Institute of Marine Engineers. The authors were Dr. E. C. B. Corlett and Dr. J. F. Leathard.

In this paper, the authors discuss progress which has been made up to the present concerning the design and construction of welded aluminum deckhouses, and, to a lesser extent, welded aluminum superstructures. Most of the work considered has been carried out in either Canada or the United Kingdom.

From the start, it is necessary to draw attention to the distinction between deckhouses and superstructures—a distinction which, in the past, has not been fully appreciated by the aluminum industry. A superstructure may be defined, generally, as a structure above the uppermost continuous deck of a vessel, having a breadth equal to the breadth of the vessel at that point, and the side plating of which is a continuation of the side plating of the hull. The contribution of a superstructure to the longitudinal strength of a vessel varies with its length in relation to the length of the vessel, and above a certain value of this ratio, where the end effects have disappeared, it may become fully effective in contributing to the section modulus of the hull. The side plating of a deckhouse, on the other hand, is not a continuation of the hull plating, and it can never contribute fully to the longitudinal strength of the ship. Indeed, upper-tier deckhouses generally accept negligible longitudinal stress.

To date, a number of welded aluminum deckhouse structures have been built in Scandinavia, Canada and the United Kingdom, but, so far as is known, only two vessels—the Great Lakes canal sister ships *Baie Comeau* and *Manicouagan*—have been fitted with welded aluminum superstructures.

The Argument for Aluminum

Clearly, ships which may be considered are best divided into two categories, *viz.*, (*a*) passenger vessels, and (*b*) non-passenger vessels.

(*a*) The adoption of aluminum in place of steel for the upperworks of passenger vessels may be justified economically by one of two arguments, or some compromise between them: —

(*i*) The retention of a similar extent of accommodation to that in steel, but a possible reduction in breadth of the main hull for equal stability, and the adoption of a finer form due to decreased lightweight. The liner *United States* probably comes into this category. The *United States* is, in a way, a paradox, as the present ability to weld aluminum alloys in the shipyard is entirely due to American technological development and research, and, in fact, the methods were mainly developed before 1951. The *United States*, therefore, although the first ship with a really large quantity of aluminum in the deckhouse structures, was, in fact, one of the last of those to have a large riveted structure.

(*ii*) An increase in the extent of accommodation, by adding, say, an additional tier, but the retention of the same basic hull form with equal stability. This class of vessel is exemplified, more or less, by the recently completed *Bergensfjord*, which has the largest all-welded deckhouse structure built to date.

It is probable that the cross-channel vessel *Bluenose*, built in Canada, represents a compromise between the two lines of approach.

Also to be considered is the effect upon stability of the 1948 Convention for Safety of Life at Sea. This has had far-reaching effects on the design of passenger ships, and it is difficult, though not impossible, to meet the requirements of the Convention for stability in the damaged condition without using aluminum for the upper tiers of deckhouses.

To obtain satisfactory intact stability, either a large metacentric height before damage is necessary, or a relatively low position of the center of gravity of the vessel must be provided. In the former case, where increased height of metacenter is obtained by increasing the beam of the vessel, the loss of stability resulting from flooding of a particular compartment also increases, and although a balance can be achieved, it is only by the summation of a convergent series for intact height of metacenter. Thus, a more direct method is to lower the center of gravity of the ship, and the fitting of aluminum deckhouses assists in this respect.

(*b*) For deadweight carriers, the economic case for the use of aluminum to save weight, and hence increase the deadweight of the ship, is marginal where there is no limitation of dimensions. Examples of vessels which are subjected, however, to such limitations are as follows:—

(*i*) *All dimensions.*—Canallers between the Gulf of St. Lawrence and the Great Lakes, where dimensions are strictly limited by the locks in the present canal system, and very high block coefficients are adopted in order to produce an economic deadweight.

(*ii*) *Beam.*—Canadian Lakes ore ships, for which a fairly rigid limitation on beam applies, due to standardized loading facilities.

(*iii*) *Draft.*—Vessels using major canals, certain terminal ports and, in some cases, bars over rivers, such as that at Demerara.

The use of aluminum deckhouses for capacity carriers is also restricted to vessels of certain specialized types. Fruit ships, of relatively high speed-length ratio, are an example of this category, as large capacity is required, and, consequently, deckhouses tend to be placed high in the ship, and stability becomes poor.

Reasons for Adopting Welding

Finally, the reason why only welded structures are to be dealt with in the paper is clear upon consideration. Shipbuilding aluminum is relatively a very expensive material and no wastage can be tolerated; welded structures will always be lighter than riveted.

Further, many practitioners regard with some suspicion the use of riveted aluminum joints in marine conditions. The corrosion product resulting when aluminum is oxidized in marine conditions is very voluminous, and, although the attack on the metal may be slight in weight or depth, trouble may result in the joints being forced open by this product. The use of welding avoids the problem completely where suitable facilities and experience are available, while the cost per foot of making a joint is very much lower with welding by the shielded inert-gas metallic-arc process than it is with riveting.

DESIGN BACKGROUND

General

Detailed methods for calculating scantlings, either directly or comparatively, are available from a number of sources. It would be better, therefore, to consider what one might call design philosophy, rather than to deal with the matter in detail.

Weight Ratios

Firstly, the point of using aluminum at all is generally to save weight. Hence, any application must be assessed initially in terms of its weight ratio compared with the steel structure that it replaces. If, however, two tiers of aluminum deckhouses are to replace one tier of steel deckhouses, then the fairest method of assessment is, alternatively, to consider the aluminum deckhouses as being in steel to normal scantlings and obtain a weight ratio, to assess the efficiency of the aluminum construction.

Many examples have been quoted from time to time for the application of aluminum and, generally speaking, weight ratios will be found to range from 0.40 to 0.55. Opinion seems to differ as to obtainable values, but it can be taken generally that, where a value of the weight ratio of 0.5 or greater is mentioned in a context which does not involve extensive compressive stresses, the design is capable of much improvement and the assumptions involved are questionable. It is possible to obtain weight ratios in service on extensive welded aluminum structures, fully approved by classification societies, not exceeding 0.40 and, in some cases, as low as 0.37. Examples of this are the canallers *Baie Comeau* and *Manicouagan*, to American Bureau of Shipping classification, where an overall weight ratio of 0.39 was achieved for both deckhouses and poop and forecastle, and the freighter *Sunrip*, where a ratio of 0.38 was achieved to Lloyd's Register classification.

Compressive Loadings

The influence, however, of compression must be taken into account. Fundamentally, the obtainable weight ratio, in compression, of geometrically similar struts in steel and aluminum is 0.586, and it will be appreciated that, should a high percentage of the structural material be loaded in compression, the weight ratio will tend to increase. In general, however, these types of loading do not occur often, and where they do, careful design can minimize the penalty which otherwise might be involved. For example, in a long bridge of aluminum construction, in a ship of some size, there is profit to be derived from framing the bridge longitudinally, even though the steel hull of the ship, below the bridge superstructure, is transversely framed. The greatly increased resistance to buckling of plating, when longitudinally framed, is of direct advantage here, and, indeed, it may well be, in a given case, that a combination of longitudinal and transverse framing would prove advantageous in reducing the weight of aluminum alloy employed, by producing panels of optimum structural efficiency.

Structural Complexity

This example leads to a further point in connection with the design background of aluminum-alloy ship structures. In steel ship structures, there is usually no great incentive to increase the complexity of the structure purely to save a small weight of material. Where large savings can be made, of course, this does not apply; but, generally speaking, there would be no attraction whatsoever in, for instance, using a combination of longitudinal and transverse framing in a welded steel ship structure, except in special cases, such as the bottom of an ore hold. In the case of an aluminum structure, however, the cost of the labor and the overhead may well be a less important item than the cost of the material, unlike the reverse case in steel, and even an appreciable increase in labor and welding cost may well be justified if a satisfactory quantity of basic material can be eliminated from the construction. In any particular case, this is a matter which requires detailed investigation.

A parallel may be struck with the use of consumable electrode gas-shielded welding in North American shipyards for steel, where, due to the high labor costs per hour involved in welding, it is economical to use the expensive equipment with its increased material cost, in order to produce a considerable saving in man-hours involved per unit length of weld, due to the increased speed available with the process. This state of affairs does not apply on this side of the Atlantic, where the use of this process is not necessarily so attractive on steel as in the United States of America and in Canada.

The necessity to produce economic structures also leads to the exploitation of a particular characteristic of aluminum alloys, *viz.*, their relative ease of extrusion. The use of special sections is expanding rapidly, with heavy bulb sections for riveting and welding used as deck beams, stiffeners, etc., while there is undoubtedly a great deal of scope for novel methods of fabrication of panels, such as by sections of plating extruded with their stiffeners integral, and by factory unit assembly of panels of specified sizes with stiffeners integral.

Standardization

The classification societies have by now adopted unofficial, but fairly standardized, methods of design approval for aluminum structures. Norske Veritas, in fact, have published Rules, but there is need for internationally agreed design and even more so for internationally agreed material. The use of heat-treatable, and non-heat-treatable alloys is one which has led to confusion, and it is probable that the best interests of all industries concerned will be served by an internationally agreed material among, at any rate, the Western nations, to be called something such as "Shipbuilding Aluminum to International Standards." This alloy would, presumably, be of the N5/6 type, and would be suitable for welding and forming by the application of heat and, at the same time, would meet all the requirements of any of the classification societies. Where repair work has to be done outside the country of origin, this may well become essential.

Corrosion Margins

Finally, the question of corrosion margins is one of interest. It is difficult to get a ruling from any classification society as to what corrosion margin is incorporated in steel scantlings in a particular case; but anyone who has been associated with the repair of old steel ships must be quite sure that as, in fact, they do not give structural trouble in spite of the considerable reduction in plating thickness, particularly beneath sheathed decks, the corrosion margin built-in originally must be considerable. Under marine conditions, suitable aluminum alloys do not corrode appreciably. Difficulties in this direction are almost entirely bound up with bimetallic joints, and the attack on the metal where corrosion product is evident, in fact, is far less than the corrosion product would lead one to believe. During the life of a hull, it is unlikely, providing bimetallic joints are correctly made, that any measurable thinning of plates will take place, and this applies even more strongly to deckhouses and superstructures.

In the case of a small tug, where the deckhouses above the main deck were of aluminum, it was found possible to effect a weight ratio of 0.28, *i.e.*, below the direct replacement weight for the two metals, by taking an arbitrary corrosion margin from the steel scantlings before conversion. The classification society in question permitted this for these deckhouses and the result was notably economic. It is suggested that this matter could be investigated and clear rulings made by the clasification societies.

TECHNOLOGICAL BACKGROUND—MATERIALS

General

Materials meeting the requirements laid down by Lloyd's Register of Shipping for the metallurgical and strength properties of shipbuilding aluminum alloys fall into two ranges, *viz.*, those termed heat-treatable and those termed non-heat-treatable. The terms are somewhat misleading in that the former refers to materials which are subjected to heat-treatment subsequent to fabrication, in order to accomplish required strength properties; the latter, however, are not subjected to heat-treatment subequent to fabrication. It is clear, therefore, that alloys belonging to the non-heat-treatable group must be used for welded structures, since there is relatively little effect on the metallurgical and strength properties of the material due to the local heating effect of welding.

Suitable alloys acceptable to Lloyd's Register of Shipping fall into the aluminum-magnesium group. The minimum requirements of 8 tons per sq. in. proof stress, 17 tons per sq. in. ultimate stress, and 12 per cent elongation on a gauge length of 2 in. may normally be satisfied by adopting B.S. NP5/6 for plate, B.S. NE6 for extrusions and B.S. NW6 for

welding wire, with magnesium content in the 3½ to 5 per cent range.

Plate

(*a*) *Properties.* — Following the considerable amount of work put into the plate during the rolling process, it is invariably possible to exceed, by a comfortable margin, the minimum strength requirements. Available evidence indicates also that even in the immediate vicinity of a weld, where local annealing must take place, the metallurgical structure of the material is such that there is little or no deficiency in the required properties.

(*b*) *Dimensions.*—There are distinct limitations to the maximum size of plate which may be produced in the United Kingdom. Breadths in excess of 6 to 7 ft. are not normally available for the thickness generally used in shipbuilding, but it is known that wider plates, up to a maximum of about 10 to 12 ft., are available on the Continent and in America, and it is believed that there are rolling mills projected which should make such plates available in the U.K. in the not too-distant future. This should have an appreciable economic effect on welded construction.

Considerable assistance could be given by the aluminum fabricators to shipbuilders by the production of plate to very close tolerances, so that no preparation would be necessary after delivery to the shipyard. It is also worth considering whether plates could be supplied ready bevelled, to provide the required edge preparation for welding.

Extrusions

The production of extrusions to B.S. NE6 to give the Lloyd's minimum proof stress of 8 tons per sq. in. necessitates a considerable amount of stretching after the material has passed from the press. In the immediate vicinity of a weld, there is a tendency for local heating to reduce the proof stress in the material to something of the order of 7 tons per sq. in., but this is of negligible importance in a stiffener plate assembly, due to the proximity of the neutral axis to the weld line. There is a certain amount of evidence to suggest that extrusions having the same alloy content as NP5/6 would not require so much stretching after production and consequently would not show the fall in proof stress near a weld. This may possibly be due to the increased manganese content normally associated with the N5/6 specification. Although little has been done in the U.K. on the subject, the production of rolled sections in N5/6, with properties similar to those of plate, might be advantageous.

A further point worthy of consideration is that alloys having a magnesium content higher than about 4½ per cent show a tendency to a particular type of corrosion in certain environments. It is therefore possible that extrusions in future may be produced to a specification—actually non-existent at present—having alloy contents similar to the NP5/6 material, which would assist in this respect.

It is worth emphasizing that the extrusion process presents almost unlimited scope to assist the designer. For instance, a section may be designed to be used at the junction between house side and deck plating. Deckhouse-corner sections and door-jamb sections are other obvious examples. One type of extrusion, first used in the Norwegian liner *Bergensfjord*, was designed to simplify the joining of two adjacent panels of deck plating, while also forming the upper flange of a deck girder.

Until comparatively recently, there were no sections which had been specifically designed for use as stiffening members in a welded ship structure. Of course, it is always possible to use toe-welded inverted ordinary angles, but, for reasons which are discussed in more detail later, an attractive alternative is to use a section having a small welding foot on the end of the web, two such ranges of section—a series of "T" bars and a series of bulb plates—which have been standardized by B.S.I. (see Fig. 1) were introduced in 1955.

Welding Wire

It has generally been assumed that some dissipation of magnesium takes place during the welding process, and that, in order to maintain the average content of magnesium in the weld at a required value, it is necessary to use welding wire having slightly higher magnesium content than the parent plate; consequently, wire to NW/6 specification has been in general use. It appears, however, that the loss in magnesium is very small, and there seems to be no reason why wire to an assumed specification NW5/6 should not be used. This proposal has the added advantage of overcoming the stress corrosion tendencies present with NW/6 as well as with NE6.

Future Proposals

Sufficient has already been said to indicate that there is every reason to press for a standard shipbuilding alloy in the near future. In view of the confusion which very often justifiably exists in the minds of those not connected with the aluminum industry, this would be a highly desirable state of affairs. Furthermore, since some difficulty is en-

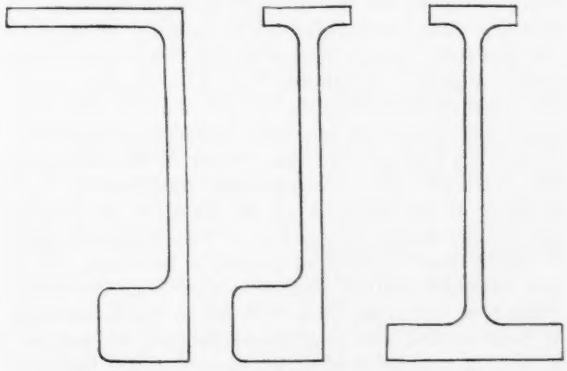


Figure 1.
(a) Bulb Angles for Riveting.
(b) Bulb Plates for Welding.
(c) Tee Bars for Welding.

countered with extrusions in meeting Lloyd's minimum proof stress, it is suggested that consideration be given to reducing this figure to a realistic 7 tons per sq. in.

Welding Equipment

For producing high-quality welding in aluminum structures, it is necessary to use some form of argon shielded-arc equipment. The argon tungsten-arc unit is normally used for sheet up to, say, ⅛ in. or 3/16 in., but for materials of the scantlings generally used in shipbuilding, the consumable electrode unit is far more satisfactory.

The normal welding gun is a rather clumsy unit, and it is sometimes difficult to provide access for the unit in all parts of the structure. Some thought, therefore, has been given to the development of a curved nozzle, but this item has not yet appeared as a commercial proposition. Furthermore, the amount of equipment which must be carried around by the operator is considerable, involving welding gun, control unit and associated tubes and cables. Consequently, attempts have been made to develop a "back-pack unit," which may more easily be carried on site work.

Within the past year or two, mechanized welding equipment has become available, and good-quality welds, both fillets and butts, may be laid at very high speeds. It is of interest to note that so-called continuous tack welds, having a leg length of ⅛ in., may be laid at welding speeds of up to 80 in. per minute.

It should be noted that coated electrodes have been used for some structures, principally in Scandinavia, but their use is not to be encouraged, especially in connection with the high magnesium-group alloys, due to the relatively low weld properties and quality obtainable.

CONSTRUCTION METHODS

General

Experience to date in this country has indicated that the production of high-quality butt welds generally requires the use of some form of backing, especially where structures are to be built by personnel relatively inexperienced in the use of aluminum under shipyard conditions. This is primarily due to the high current density of the consumable-electrode welding torch, with the corresponding danger of burning through and loss of control. Backing may take the form either of temporary metal strips, held in position on the back of the plate to be welded and subsequently removed, or it may be permanent, in which case it would, of necessity, be of aluminum and form part of the structure (see Figs. 2 and 3).

Plate of up to at least 5/16 in. in thickness may be butt-welded into permanent backing in one run. A weld of similar quality, using temporary backing, would normally require back chipping and a further sealing pass. The total footage of butt welding, using permanent backing for a given deckhouse structure, would generally not exceed the total footage for a similar structure using temporary backing, and it is submitted that the best solution is to design the structure to accommodate this permanent backing.

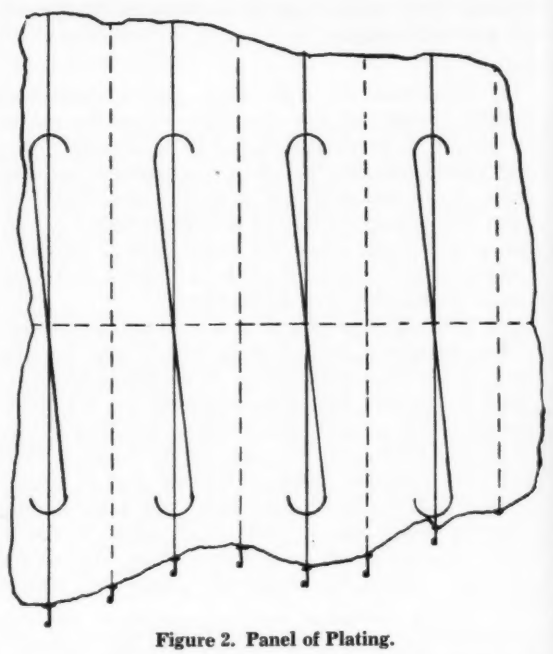


Figure 2. Panel of Plating.

Several ships are in existence, however, in which the construction of the large deckhouses is in accordance with normal steel practice and the results have been successful. The deckhouses in the *Sunrip*, owned by Saguenay Terminals, Ltd., and built in Canada, were designed in this fashion, and represented the largest all-welded aluminum ship structure to be built at the time, but it is known that considerable difficulty was encountered in restricting distortion within acceptable limits.

The ferry *Bluenose*, however, built immediately

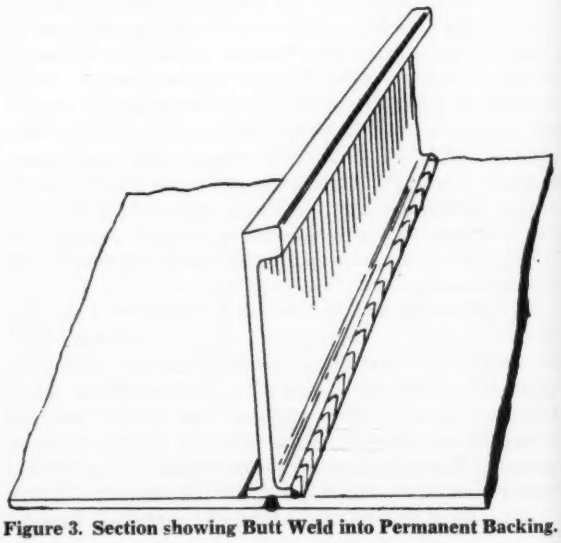


Figure 3. Section showing Butt Weld into Permanent Backing.

after the *Sunrip* at the same shipyard, with the same methods, showed a much reduced level of distortion due to the experience gained on the *Sunrip* structures. On the other hand, the deckhouses in the Norwegian American *Bergensfjord*, built in Britain recently, and representing a considerably larger structure, were built to a design mainly incorporating permanent backing bars, with the result that distortion was considered to be less than would be encountered in a similar steel structure.

Naturally, the amount of distortion is also related to speed of welding. The range of cooling from the freezing of the molten-metal pool to ambient is approximately half of that relating to steel, but the coefficient of expansion is approximately double that of steel, so that cooling from molten to ambient produces approximately the same contraction. However, if welding is not carried out fast enough, heat leaks from the weld at a high rate in aluminum, due to the high coefficient of conduction. The resulting expansion in the surrounding structure changes its dimensions and produces distortion, which is finally locked in by the weld itself. The answer to this is to use fast welding methods and, wherever possible, mechanical welding equipment.

The Use of Permanent Backing

Acceptance of the use of permanent backing for butt welds requires that all plates run in the same direction as the associated stiffening members. For instance, in a transversely-framed deck, plates must run athwartships, and have a width equal to some multiple of the beam spacing. Similarly, house sides should be plated vertically. Should plates become available in the United Kingdom having a width of 7 ft. 6 in. to 8 ft. 0 in., however, deck butts in the normal house could be arranged on every third beam, instead of every second beam as at present, and house sides could be plated longitudinally, using the maximum length of plate available.

Procedure

The system proposed is ideally suited to prefabrication especially in conjunction with mechanized welding. For instance, panels of deck plating may be produced completed in the shop and then joined together on site, using beams or specially designed girders as permanent backing.

Prefabrication of panels is most simply carried out using a jig, whereby stiffeners are wedged into slots set at the required spacing, and the plates are laid on the welding feet, leaving a given air gap. Tack welds must be laid at fairly close intervals to ensure that both plates are hard down on to the stiffener, but it is then quite possible to weld from one end to the other, without fear of unacceptable distortion occurring. It has not been found necessary to restrain the plates in any way when completing butt welds.

On completion of the butt welds, the panel is turned over and dogged down, so that lateral movement is not restricted. Intermediate stiffeners and/or girders are then tacked in place and continuous welds laid on all members so that they are completely enclosed. Welding sequences are similar to those adopted for steel construction, in that welding should generally be carried out from the center of the panel working to the outside. It is quite possible to use a machine welder to lay a fillet, starting at one end of a stiffener and running out to the other. Once again the importance of adequate speed cannot be over-emphasized.

There are several points of detail which should be observed during construction. Very often, stiffening members do not run the full length of a butt weld, and it is necessary to insert temporary backing of steel or aluminum, which must be removed after completion of the weld. Such temporary backing also serves as a run-on or run-off tab. It must be remembered that torch clearances greater than with steel welding should always be left, so that welds may be made continuous around all members. When panels have been erected on the ship, it is necessary to complete butt welds as soon as possible, so as to prevent dirt lodging between the plates and the backing. Very often, a jet of dry compressed air is directed on to the work and this is useful for removing moisture and dirt. Removal of grease by the use of white spirit and scratch-brushing is also essential before any welding is carried out.

EXAMPLES OF APPLICATION

A number of applications to interesting vessels are described herewith. These are divided into three categories, *viz.*, (1) structures in service, (2) structures building, and (3) design study of a typical passenger/cargo liner.

STRUCTURES IN SERVICE

(a) Canal/Lake Ships "Baie Comeau" and "Manicouagan"

These twin-screw canal/lake ships are of the standard size. The block coefficient is very high. This type of vessel is interesting, as it represents the end of an evolutionary process where, except by radical technological change, improvements in carrying capacity cannot be achieved. Basically, the hulls are of the same dimensions as those of the canaller *Franquelin*, built before the Second World War, and the deadweight/displacement ratio is about the same on a block coefficient as high as 0.88.

Basically, the deadweight/displacement ratio has been maintained by the extensive use of aluminum in all erections above the main hull. The poop and forecastle, together with the deckhouses thereon, are of welded aluminum construction in NP5/6 plate and NE6 extrusions. Welded by consumable electrode equipment, the weight ratio achieved was about 0.39. A preliminary design was prepared, which showed a weight ratio of the order of 0.5, and, on this basis, the application was not economic. However, with the lower ratio, it was shown that every ton of aluminum installed produced a most acceptable increase in earning capacity, which, in

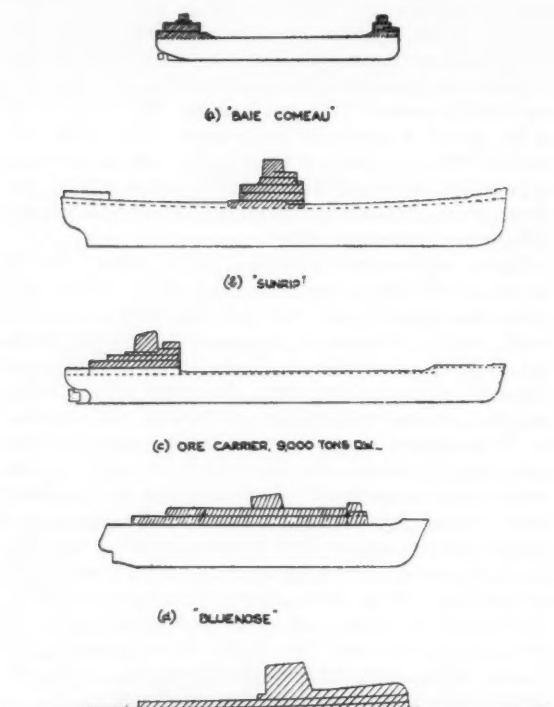


Figure 4.

fact, was sufficient to write-off the complete capital cost of the structure in approximately six to seven years. Fig. 4(*a*) shows the extent of the aluminum structure.

These ships have now been in operation for some time. Very little trouble has been experienced, although the bimetallic joint between the aluminum and the steel has not been entirely satisfactory, due to extrusion of the gasket material. This joint was designed to bear the weight of the superstructure and houses, and it is probable that such a design should incorporate weight-bearing shims, which would relieve the gasket. This gasket material should be of a strong fibrous nature (not plastic material only), as under constant pressure it tends to extrude.

(b) Ore-carrier "Sunrip"

Initially, it was proposed to build the midship deckhouse of the *Sunrip* in aluminum alloy of the North American type 65S and of riveted construction. For economic reasons, this was changed to welded construction. It was apparent that this latter proposal did not represent optiumum practice, due to the poor weld properties in the heat-treatable material, and the choice finally fell upon a material of the NP5/6 type with NE6 extrusions. A final weight ratio of about 0.38 was achieved, the total weight of aluminum in the deckhouses alone being of the order of 70 tons.

Aluminum alloys were used extensively throughout the remainder of the vessel, and the total amount incorporated in the ship was in excess of 200 tons, but the remaining applications are not relevant to the subject under discussion.

The cost of each deadweight ton gained by the use of aluminum was approximately 50 per cent more than that of the basic ship, but, again, this can be strictly economic, as the increased deadweight is obtained without any proportionate increase in dimensions, H.P., crew, fuel consumption or other operating factors.

The ship has been in service for over two years and the aluminum installation has proved extremely satisfactory. An interesting point in this connection is that the exterior surface has been left completely unpainted after being wirebrushed subsequent to completion. This surface has now weathered to a pleasant grey color, and examination leads to the conclusion that it will remain satisfactory during the entire life of the vessel. Fig. 4(*b*) shows the profile of the ship, with the aluminum deckhouses indicated.

(c) Ferry "Bluenose"

The ferry *Bluenose* was constructed in Canada shortly after completion of the *Sunrip*, by the same shipbuilders.

All the deckhouses above the promenade deck are welded aluminum structures, and a total of approximately 110 tons of material was used in all (see Fig. 4(*d*)). Due to the adoption of design methods similar to those of the *Sunrip*, a comparable weight ratio was obtained. The plate was to Alcan B54S-F specification, extrusions to Alcan A56S, and welding wire to Alcan 56S.

The system of construction was also similar to that on the *Sunrip*, and it is understood that difficulties due to distortion were appreciably less—probably due to the experience gained by the shipyard in the construction of the previous ship. It is of interest to note that, in many cases, beams and stiffeners were attached to the associated plating by intermittent welding, and that beam knees were lap welded to beams and stiffeners; these procedures differ somewhat from those shown to be satisfactory by certain experience gained in the United Kingdom.

(d) Small Structures

In the comparatively early stages of development work in this country, several small welded structures were built in various shipyards, either for test purposes or for fitting on board ship. For example, a welded wheelhouse top was constructed, and useful experience was gained in the use of welding equipment under outside conditions. All welding was done by hand, and all butts were arranged to be permanently backed.

A wheelhouse front and top were produced, and

this time a considerable number of the welds were laid by machine.

(e) Liner "Bergensfjord"

The basic hull design of the *Bergensfjord* is very similar to the *Oslofjord*, built some years ago, but, by a more extensive use of aluminum, it has been found possible to increase the number of passengers by some 67 and to enlarge the area available for public rooms.

Approximately 410 tons of aluminum was used for the four upper tiers of houses, funnel and other items; see Fig. 4(*e*). Apart from certain beam/girder brackets, the structure was all-welded, using the system of permanent backing bars. The structure on this vessel represents the largest welded aluminum job so far constructed in a British shipyard, and, possibly, in the world.

STRUCTURES BEING BUILT

(a) Ore-carriers

There are a number of interesting installations under construction at the moment. Four ore-carriers are being built for Canadian owners, all of which incorporate considerable quantities of aluminum alloy. There are two classes of vessel, one of 9,000 tons and the other of 16,000 tons, with machinery and all deckhouses aft, these houses being constructed of welded aluminum.

The same design approach as adopted in the case of the *Sunrip* has been used, weight ratios obtained being approximately 0.38 to 0.39. The constructional methods adopted approximate to those used on the liner *Bergensfjord, i.e.*, deck plating and house plating are run transversely and butts are located on every second beam or stiffener. The houses are being constructed in large prefabricated units. Fig. 4(c) shows a diagrammatic profile of one of these ships, at present under construction in Germany.

These four vessels, with the *Sunrip*, will constitute a most interesting and impressive quintet of ships, with very good deadweight/displacement ratios, and low weight ratios in their aluminum structures. They illustrate forcibly the fact that it is possible to assume, with confidence, a saving in weight of approximately 1.6 to 1.7 tons for every ton of aluminum fitted.

(b) Large Passenger Ships

It has been reported that two new passenger liners, at present on order in the United Kingdom, are both to incorporate some 800 to 1,000 tons of aluminum in the deckhouse structures. It may confidently be assumed that a great deal of welding will be used.

DESIGN STUDY—TYPICAL PASSENGER/CARGO LINER

A study was carried out to ascertain the effect of replacing the series of steel deckhouses on a passenger/cargo liner by a series of aluminum deckhouses having an extra tier. Modifications to the basis ship below the strength deck, due to the fitting of aluminum houses, were to be kept to a minimum, while the extra accommodation would allow a considerable increase in the number of passengers which could be carried. Thus, the additional material cost of the aluminum structure should be balanced over a certain period by an increased earning

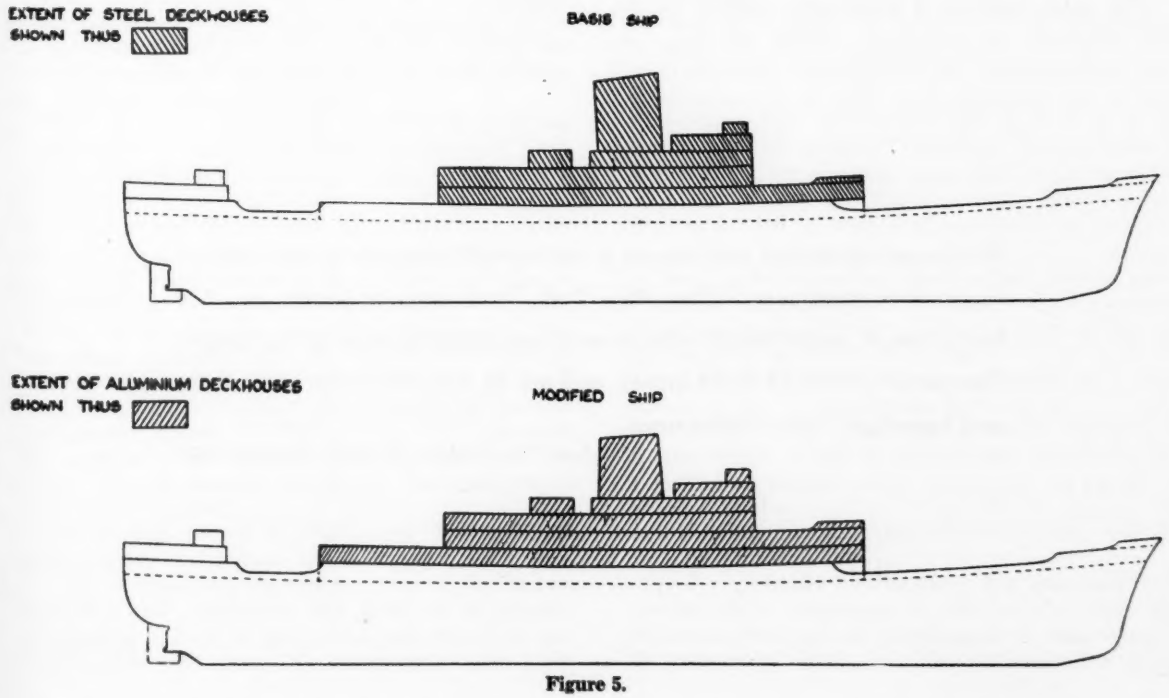


Figure 5.

capacity; increases in overhead should be small, since no change was proposed in the basic hull design.

A modern one-class passenger/cargo liner was chosen as a representative of the class of ship to which the analysis could be applied. From a design view-point, the problem is primarily concerned with stability. Very briefly, the moment of the aluminum structure about the base-line of the ship should not exceed the moment of the basic steel structure. This would allow the more extensive series of aluminum houses to be adopted without any modification to the basic hull form, since the stability would be unaffected.

Estimates were made for the weight of the basic steel structure and for the aluminum structure, using accepted design principles. By adopting British Standard shipbuilding sections, reasonable weight ratios were obtained, where applicable, of an average of about 0.39. Fig. 5 shows the extent of the original steel houses and increased extent of aluminum houses.

Various assumptions were also made with regard to fire-protection, number of crew, increase in fresh-water capacity, etc., for the modified design. Method (1) was adopted for the fireproofing of all the houses above the bridge deck. An increase in the number of catering staff was required, and, by a redesign of the space available for the crew, the additional stewards were accommodated at a standard slightly lower than the original ship. If no additional fresh-water were carried, the allowance per day for the full complement of passengers and crew was still considered to be reasonable.

The total number of passengers carried in the basic design was 106. In the new design, the introduction of the extra passenger deck allowed the number to be increased to 170. The total available area for public rooms on the new design was practically comparable in relation to the number of passengers as on the basic design. It was necessary to enlarge the restaurant, and this was achieved by eliminating a small upper 'tween-deck cargo space.

It was found that, by the use of aluminum, a total of 64 more passengers could be carried at the expense of 18 additional crew and a loss of cargo space of about 5 per cent.

CONCLUSION

Slow but steady progress is being made in the marine field by aluminum construction. The technological advances in the past few years have been considerable and, indeed, have cleared most, if not all, of the technical objections that could have been raised in 1950. The greatest single advance in this period has been the introduction of the consumable-electrode arc-shielded welding equipment in association with the NP5/6-type material. This has made practical shipbuilding a possibility, and it may be concluded that the biggest remaining obstacle to the rapid expansion of welded marine structures is the cost of the material.

The authors recommend, however, that several loose ends on the technological side need urgent attention. These are as follows:—

(1) Standardization of one type of aluminum alloy acceptable to the classification societies.

(2) Inauguration of Rules by the classification societies.

(3) Development of a Code of Practice for welding.

The longest all-welded steel beams in the United States are found in a highway span viaduct near Suffern, New York. The beams, or girders, are 234 feet in length, and 4 feet 8 inches in sectional depth for most of this length. Flanges vary from 18 to 24 inches, and are ¾ inch thick. The web plates vary from ⅜ to ½ inch in thickness.

—from "The Welding Journal," October 1957

LIEUTENANT (JG) JOSEPH F. A. ORMSBY

WORKLOAD FORECASTING ON AN ELECTRONIC COMPUTER

THE AUTHOR

Graduated from Rensselaer Polytechnic Institute in 1950. From then until the Spring of 1955, he worked at R.P.I. in the various capacities of instructor in the Department of Electrical Engineering, assistant project engineer on a Signal Corps project, and research associate in the Computer (analogue) Laboratory Department. During this period he also received his M.E.E. and M.S. (math) degrees from R.P.I. He entered the United States Naval Officers Candidate School in May 1955, and received his commission as an Ensign in the Naval Reserve in September 1955. Upon assignment to Boston Naval Shipyard, he worked as a ship superintendent. Later he was assigned to the Production Analysis Officer as an assistant on electronic data processing. His interest in this area is reflected in the present article.

PREFATORY NOTE

The past 20 years have been one of constant evolution for U. S. Naval Shipyards. This is particularly evident in the great increase of administrative problems. For example, the Production Officer of 1937 is not recognizable in his successor today nor will today's Production Officer be at home in the Shipyard of 1977. The Production Officer has shifted from the professional engineer of the thirties to the administrator of the fifties.

This evolution was clearly established with the introduction of the Production Planning and Control System about 5 years ago. Under this program elaborate staff organizations were set up to assist the Production Officer and Shop Masters. From these have come studies on shipyard methods and procedures which are starting to result in shifts of responsibilities, improved practices, and lower costs. These trends in savings should increase in the next few years. However, the staff organization itself is cumbersome and ineffective in handling the vast amount of data involved in these improved practice procedures. These problems, of necessity, demand the application of data processing equipment to develop the vast amount of reports and data faster and more completely.

The introduction of EDPM at the Boston Naval Shipyard will take place within a year. The introduction of this computer in the field of Production Planning and Control in the shipyard is already generating a flow of possible applications on administrative problems. One such application is in the field of workload forecasting and scheduling. This is a rather peculiar application in that it found little in the way of precedence and was approached purely in an exploratory fashion. The approach falls between the categories of data processing and engineering.

The work described in the article is a first attempt to apply the decision making ability of the computer to generate realistic forecasts based on ship manning requirements and yard manpower capabilities. In addition, the accuracy of source data is to be maintained by constant revision. This revision is based on more accurate and current information controlling the ship manning data. The revision process is tied in with the scheduling application. At the time this article was written, the integration of the scheduling application into the forecast problem with its consequent development of manning based on work schedules and job estimates had just begun. The approach indicated in Phase I of the article, based on standard curves applicable to more than one ship, is an attempt to evolve a first order approximation for overhauls more than 3 months in the future. Under 3 months the procedure will revert to a manning curve peculiar to the particular ship's workload and planning status. This should result in some modifications to the calculational details in Phase I.

It is hoped that by discussing the approach in its present form, discussion in the problem area will be stimulated and an interchange of ideas and information will result. It is also anticipated that con-

tinuing work at this facility will result in an expanded approach involving Phase III and the integration with the scheduling phase mentioned above and briefly in the article.

Finally, it is intended to report any significant developments tending to make the approach more practical and accurate for our application.

INTRODUCTION

The work of today's naval shipyard involves the repair and improvement of existing ships, the conversion from one ship type to another, and the construction of new ships. The term overhaul is generally applied to the repair effort while the term availability is generally employed to designate any of these three work efforts on a ship. However, for our purpose we shall adopt the general term overhaul, unless otherwise specified, to describe the repair, conversion, and construction projects.

As the title of the article suggests, we are interested in a workload forecast. This is a tabulated report, for each shop and the yard as a whole, of the predicted weekly workload demands in units of average men per day. It covers each ship being worked within the next six months. It also includes the predicted weekly manpower available and shortage or surplus summary during the six month forecast period.

At present, these reports are obtained biweekly as an electric accounting machine application based on manning estimates derived manually and indicated on mark sensed cards. The reports are used both by management and the productive shops. Briefly, the former use them as a signal for establishing possible revisions in the future workload and work force patterns while the latter employ them as a guide for distributing their manpower on the ships being worked. Thus, the workload forecast constitutes an important tool for the control of production levels to minimize workload shortage or surplus resulting from the erratic and complicated work patterns of a naval shipyard.

The present method of producing workload forecast reports at the Boston Naval Shipyard has prompted a study to apply electronic data processing equipment in this area for effecting a rapid means of obtaining an accurate and realistic forecast. It was felt that such an approach could result in the elimination of the entire burden of manually developing realistic manning estimates (in units of average men per day) as well as a significant reduction in card preparation time, volume of cards handled, and machine running time. In addition it was hoped that more extensive and varied reports could result from a computer solution.

It was with these aims in mind that a study was begun on a computer approach to workload forecasting. During the first six months considerable development and revision on various approaches took place. Most of this work, without the use of tape storage, was concerned with that phase of the problem (Phase I) which computes the optimum forecast estimates. These optimum estimates consider the ship as a unit divorced from any influence due to work on other ships. During the next two months, which extends to the present time, this work was again modified to fit into the development of Phase II. Phase II calculates realistic forecast estimates using the overall shop status to modify the optimum estimates and thereby to produce a compatible solution. During this later period the expanded approach was developed for use with an intermediate size computer with tape units. The development has resulted in an approach which seems to come close to satisfying the aims mentioned above.

An appreciable amount of effort was required to apply the schemes of Phase I to the computer originally considered. The limitations of computer drum space as well as the restriction on areas for reading in and out information necessitated, at times, rather elaborate data handling routines. Both of these factors also contributed to make space limitations a fundamental restriction. The later adoption of a computer with a larger drum storage and non-restrictive read-in and-out areas aided greatly in reducing space limitation problems and provided for the possibility of including on the drum those routines and storage areas required by Phase II in the development of realistic manning estimates.

Figure 1 shows a flow chart of the computer system associated with this problem to include Phase I and II and later additions (Phase III). Phases I and II may be worked without the use of the random access unit on a less flexible basis.

PHASE I

It is not the purpose of this paper to enter into a detailed description of the actual program but rather to indicate the approach used and the general make-up of the program.

At present there are two major phases associated with the program. Phase I results in the calculation of optimum manning estimates as its main feature. These estimates in units of average men per day are based on computations which consider each ship *per se* affected by historical precedents and present actual manning. The computer develops the ship's optimum estimates for each week in a six month forecast period. This figure is derived fundamentally from a basic manning curve which is stored at present as tabular data on tape. The estimate is then modified for compatibility with the present rate of actual manning. What might be termed an arbitrary discrete approach has been considered and is now being used. The modification procedure also has been considered using such correction factors as $\frac{1}{2}(x^a + x^b)$ and $x^a[1 + f(x)]$ where $f(x)$ is an exponential type function containing b, with a and b as determinable constants and x as the per cent of overhaul period completed.

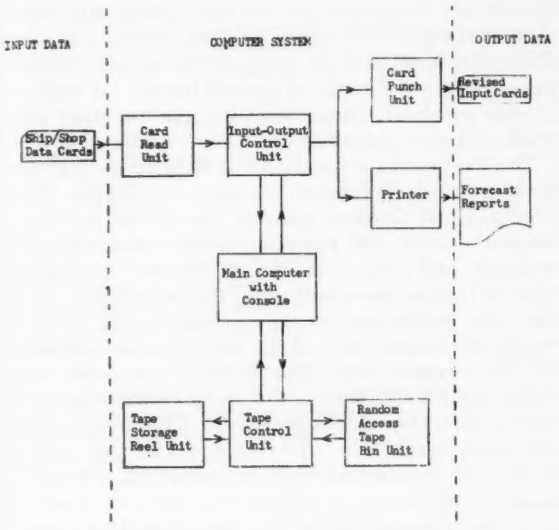


Figure 1. Flow chart of computer system.

Both methods adjust the optimum estimates for all weeks in the forecast period to take account of the trend in actual manning up to the week of computation and to redistribute any lag or lead in actual manning total at the computation week over the remainder of the overhaul. Any alteration in the total manning estimate during an overhaul is considered by the computer as an equivalent lag or lead in actual manning and is treated accordingly.

Figures 2 and 3 illustrate graphically the manner of this correction for a lag in actual manning where the computation week is at the 50 per cent point of the overhaul period.

The basic manning data are either standard data based on a statistical average for the ship type in question in each shop or a particular set of data

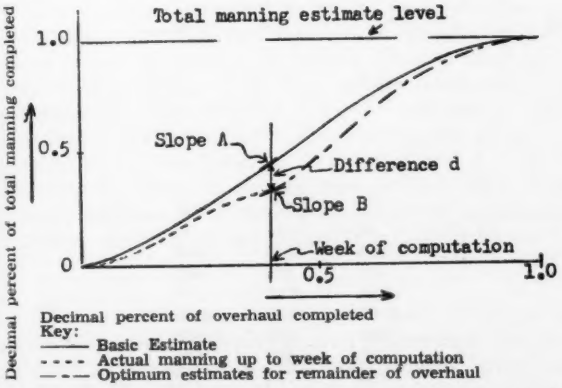


Figure 2. Development of optimum forecast estimate based on an untolerable difference d (shortage) between basic manning estimate and actual manning at the week of computation accounting also for the difference in slopes A and B.

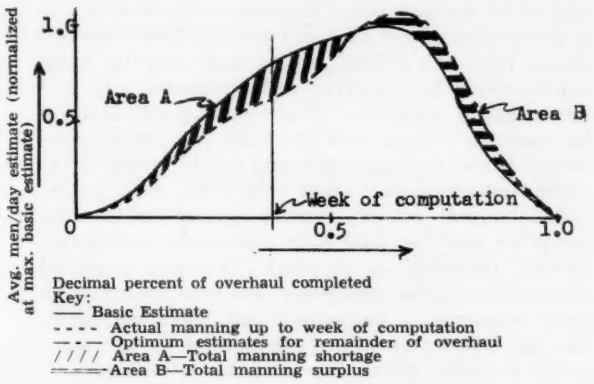


Figure 3. Development of optimum forecast estimate based on an untolerable shortage (Fig. 2) which adjusts areas A and B to equal values.

suited to the ship in question if this ship's manning in the shop differs appreciably from the standard. Two sets of basic estimate data are used for each ship and shop. One is for ship work exclusive of drydock work. The other is for drydock work only. This arrangement provides for flexibility in locating the drydock period within an overhaul. These two data are combined to produce the overall basic manning estimate for the ship and shop under consideration. The approach is illustrated in Figure 4.

Polynomial fitting, using the form $\sum_{i=1}^{k} a_i x^i$ to at least the fifth order and then calculation of manning from these polynomials was also considered. However, the eventual application of the computer to the automatic development of manning curves from standard job operations as well as the present production of individual ship manning curves for various studies makes the use of tabular manning data more desirable.

The same format is used on all shop and yard printed output forecast reports for Phases I and II. It is to be understood that a yard forecast is the

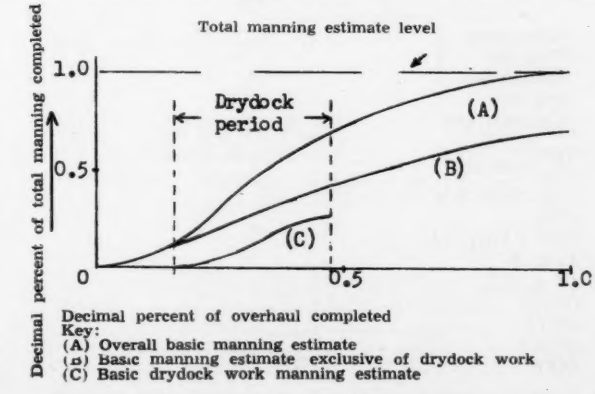


Figure 4. Fitting together of regular and drydock basic estimates to produce overall basic manning estimates.

sum of all the individual shop forecasts. Such a sum is performed within Phases I and II. These forecast sheets from the printer list for each ship its name (abbreviated to 7 letters) and designator (up to 4 letters and 4 numbers), total manning estimate, total manning to date, and 13 weeks of manning estimates. It also includes estimates for 13 weeks on 11 other items including other ship work, shop potential data, and certain results derived within the computer such as total ship work and overall difference (shortage or surplus). The shop potential data include gross manpower, net manpower, overhead, supervisory personnel, and leave estimates. The last 3 items constitute the basis of the net manpower estimate which the computer develops.

Table I is a sample of a forecast sheet format showing some of the 13 weekly periods. At present 26 weeks are used in a forecast. Phase I forecast sheets reflect the optimum forecast estimates while Phase II forecast sheets are based on the modification of these optimum forecast estimates to produce the realistic forecast estimates.

The first Phase accepts data from input cards which may contain either of 2 types of information. Therefore the input cards are designed with 2 formats. The first card format precedes the second during the computer run on each shop. For each shop there is one card of the first format for each ship considered and 14 cards of the second format, since there are 2 cards of second format for each of 7 items involved. These items include the other ship work and shop potential estimates mentioned above.

The first card format contains data about the ship such as its identification, the start and length of its overhaul and drydock periods, the actual work expended during the previous week, total manning estimate, and other control information. The second type of format cards following the calculation of all the ship estimates contain estimates for the 26 weeks of forecast on 7 of the last 11 items indicated on the forecast sheet (Table I). These later estimates are almost always the same as those appearing on the shop forecast sheets. The new format cards are created by the computer. In the case of cards with the second type of format, an allowance is made, by means of a shift, for one new week to cover the forecast period for the succeeding week's run. Most of the computer routines associated with this second format card are of a data processing nature.

Table II illustrates the formats of the card used as input to the computer.

TABLE I—*Sample shop forecast sheet*

Name	Desig.	Est.	Act.	713	714	715	Remaining Weeks
Fessenden	DER142	12175	7490	270	300	305	
•							
•							
(Remaining)							
(Ships for)							
(Regular)							
(Overhaul)							
ATKA	AG152	2100	550	79	119	128	
•							
•							
(Remaining)							
(Ships for)							
(Restricted)							
(Overhauls)							
Gyatt	DD712	87250			50	90	
•							
•							
(Remaining)							
(Ships for)							
(Conversions)							
(and New)							
(Construction)							
TEK				120	120	120	
YDC				14	14	14	
TOT SHIP WK				4664	4710	4674	
MFG				461	458	443	
TOT PROD WK				5125	5168	5117	
FORCE				6906	6906	6863	
IV A				501	501	496	
OVHD				850	850	850	
OUTS				756	756	709	
AVAIL				4799	4799	4808	
DIFF				–376	–369	–309	

Note: EST. = Total manning estimate; ACT. = Total manning to date; and 713, etc., refer to period.

TABLE *II—Contents of input card using two information formats*

FORMAT 1

Col.	Item
2–8	Ship Name
9–16	Ship Designator No.
17–20	Code No.
21–22	Shop No.
23–26	Period
27–30	Start Date of Availability
31–34	Start Date of Dry Docking
35–37	Length of Availability
38–40	Length of Dry Docking
41–46	Estimated Total Manning
47–52	Actual Manning to Date
53	Work Days in 1st Week of Availability
54	Work Days in 1st Week of Dry Docking
55–57	Days of Availability Completed
58–60	Days of Dry Docking Completed
61–77	Control Constants
78–80	Actual Manning for Previous Week

FORMAT 2

Col.	Item
2–11	Title
21–22	Shop No.
29–32	Avg. men/day potential for week 1 or 14
33–36	" 2 or 15
37–40	" 3 or 16
41–44	" 4 or 17
45–48	" 5 or 18
49–52	" 6 or 19
53–56	" 7 or 20
57–60	" 8 or 21
61–64	" 9 or 22
65–68	" 10 or 23
69–72	" 11 or 24
73–76	" 12 or 25
77–80	" 13 or 26

During Phase I the computer reproduces the first card format with updated information and with blanks in the space assigned to previous week's expenditure of actual manning. The later information together with any corrections is key punched into the card prior to each week's run. The first phase computations using, in part, the first format card data are repeated for all the ship input cards numbering up to 50 per shop.

The computations produce the optimum manning estimates as mentioned above on a per ship basis for all weeks in the 26 week forecast. These calculations take account, through a table of exception weeks, for variable length work weeks. Phase I also prints out one line per ship on the shop forecast report (see Table I) covering the first 13 weeks. After the entire first 13 weeks forecast is printed for a shop, a routine then prints out the entire second 13 weeks for the same shop before moving on to calculations for the next shop. There are 13 shops in the run.

The routines indicated so far in the production of manning estimates are flexible in nature in that they allow for general situations. That is they take account for instance of ships whose overhauls are in progress, just over, or have not yet begun. The routines take advantage of the computer system's potential for handling up to 5 input and 5 output information formats during the problem run. The block diagram of Figure 5 displays, in a general fashion, the computer routine involved in Phase I.

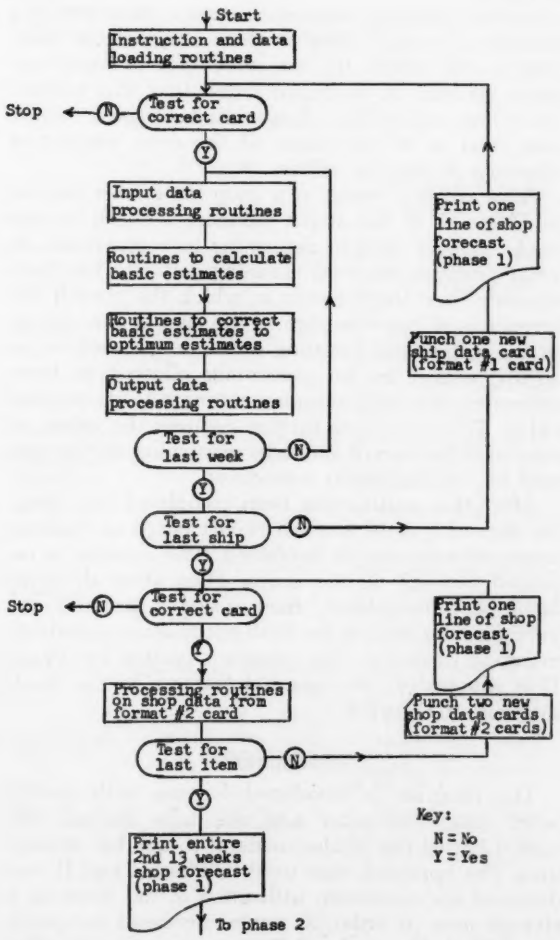


Figure 5. Simplified block diagram for program of Phase 1.

PHASE II

The second Phase examines for each week in a shop the overall differences, that is shortages or surpluses, as measured by the item labeled "diff." in Table I. This item is the difference between total productive work and net available force, labeled as "tot. prod. wk." and "avail." respectively in Table I. Any shortage or surplus is compared to a tolerance level for the shop under examination. If the differ-

ence is above tolerance the over amount is distributed into the ships by modification of Phase I optimum estimates in a fashion governed by priority constants.

These priority constants are developed in this phase. They are accounted for by such considerations or factors as percent of overhaul completed at the week under consideration, the work progress in the overhaul at the week of computation, and any other criteria, such as policy decisions, which are lumped into a third factor. The percent of overhaul completion is used as an exponent in an exponential factor which measures with greater sensitivity whenever the week under consideration is close to the end of an availability. The three influencing quantities are used to form a product which is called the priority constant.

The adjustments to the optimum estimates of Phase I are made so as to produce manning estimates which do not go beyond a set percentage of the basic estimates. Any over amount in shortage or surplus remaining after all ships for the week under consideration have been considered is absorbed in a second adjustment pass on those ships whose manning is still within the set percentage of basic estimate allowed. A study indicated that this method has a high probability of providing sufficient correction, that is of absorbing all the over amount of shortage or surplus values.

After all the weeks in a shop have been treated in Phase II in the above manner, a check is now made on each ship to determine how much and in what direction its total manning estimate has been altered. Then those weeks in which the overall difference is of opposite sign to the sign of the change in the ship's total manning estimate are used to readjust, within the set percentage allowed on basic estimates, the total manning estimate to its original value. This procedure further reduces the values of overall difference of shortage or surplus, as the case may be, for the weeks considered.

After this routine has been completed in a shop, the second type of forecast report based on realistic manning estimates is produced. The routine is repeated through all the shops. Then after all shops have been completed, final routines produce the yard forecast reports for both optimum and realistic manning estimates. The program routine for Phase II is illustrated, in a general fashion, in the block diagram of Figure 6.

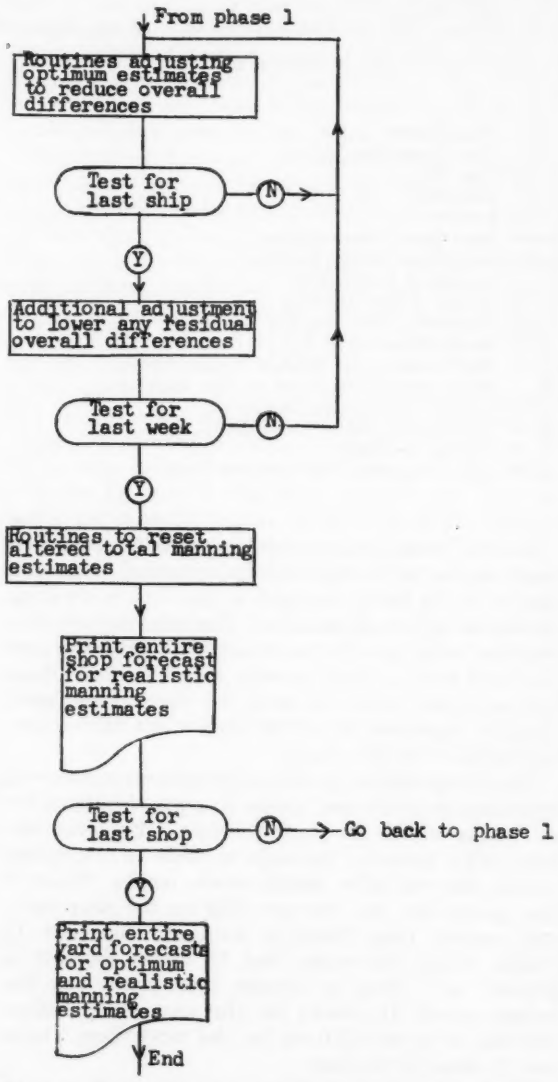

From phase 1
Routines adjusting optimum estimates to reduce overall differences
Test for last ship
N
Y
Additional adjustment to lower any residual overall differences
Test for last week
N
Y
Routines to reset altered total manning estimates
Print entire shop forecast for realistic manning estimates
Test for last shop
N
Go back to phase 1
Y
Print entire yard forecasts for optimum and realistic manning estimates
End

Figure 6. Simplified block diagram for program of Phase 2.

CONCLUSION

The program is developed for use with a 4000 word drum computer and one tape storage reel unit. Limited use is also made of a tape bin storage unit. The approach now used in Phase I and II was designed for maximum utilization of the drum as a storage area in order to attain increased computer speed. With Phases I and II the optimum and realistic yard estimates are stored in up to 200 records on the tape bin unit. The tape reel unit stores regular and dry dock manning percentages in up to 2250 tape records. Schemes for obtaining manning plots from the output printer are also considered. These plots will aid in making decisions to rerun for shifts or eliminations in availabilities. Greater flexibility and the possibility for reruns using only a minimum of Phase I calculations will be realized for Phase III by maintaining estimates for all shops on the tape bin unit.

It may happen that it is not possible to completely readjust the total manning estimate for a ship back to its original value in Phase II. This may be due to (1) an insufficient number of weeks where the difference is of opposite sign to the sign of the change in the total manning estimate, or (2) the restriction placed upon the amount of correction by the basic manning estimate tolerance. In such a case we may

reduce, starting with the last week in the ship's forecast, the correction on overall difference in those weeks where the realistic and optimum estimates differ in the same direction as the change in total estimate, by using optimum estimates or reduced realistic estimates until a balance in total manning estimate is reached. After all ships have been treated, where required, in this manner, there will usually result overall differences above the accepted tolerance for the shop. This would suggest later application of such procedures as loan and borrow between shops, change in leave or overtime estimates, or shift and/or elimination of availabilities. It may also happen that conditions make it impossible to produce any realistic ship estimates and still keep the total manning estimate for the ship at its original value.

A preliminary approach to determining and handling the difficulty might proceed as follows. A ratio r_i of the number of shortage weeks to surplus weeks or its reciprocal for a shop is tested prior to entering the calculations of Phase II. If $a \leq r_i \leq 1$ where a is a predetermined constant, then we enter Phase II calculations and form $r_t = r_i r_s$ for each ship. The r_s factor is a measure of the per cent of availability of the ship contained in the forecast period. If $r_t < b$ where b is a predetermined constant, then Phase II is not applied to this ship in the shop under question. Whereas, if $r_t \geq b$, Phase II is applied. In this last situation we may still require the procedure suggested in the previous paragraph when the change in total manning estimate cannot be returned to its original value by Phase II calculations.

Now for a shop where $r_i < a$ we do not apply Phase II. Rather we go to a table, obtain an f_i weighing factor, apply to it a sign which indicates shortage or surplus, add it to a sum Σf_i being carried, and proceed to the next shop.

After all shops have been considered we check $S = \Sigma f_i$. If $S > c$ where c is a predetermined constant, we may consider the possibility of shifts and/or eliminations of availabilities aided by the examination of forecast reports and plots from the printer. In this case and when $S \leq c$, we may consider loan and borrow or change in overtime and leave estimates as remedial procedures.

The procedures and problems briefly discussed above form the problems and basic approach leading to the program of Phase III. The programs of Phases I and II together with that of Phase III, including even the possibility of automatic decisions to eliminate or shift availabilities, seem well adapted to the computer system adopted.

This start in the application of workload forecasting to a computer in the approach outlined above should provide a first answer to the aims listed at the beginning of this paper. Aside from the derived benefits of fast, accurate, flexible and extensive forecast reports, certain other advantages specific to the procedures at Boston may be mentioned. In comparison to presently employed procedures they are:

(a) Standard file of cards reduced from 9000 to 2000.
(b) Total man hours required per run reduced by factor 2:1.
(c) Total machine time reduced by a factor of 4:1.
(d) The production of weekly rather than bi-weekly reports.
(e) The production of optimum as well as realistic forecasts.

When compared to a weekly run producing optimum and realistic estimates using present techniques, the computer approach results in the following savings:

(a) Card file reduced from 18,000 to 2000.
(b) Total man hours required per run reduced by factor 7:1.
(c) Total machine time reduced by factor 5:1.
(d) Average monthly savings about $1500.

APPENDIX

LIST OF EQUIPMENT REQUIRED

a) Card Read Unit	089 Collator (IBM)		a 240 card/min. card reader modified to tie into Cardatron System (can also be used off line).
b) Card Punch Unit	523 Gang Punch (IBM)		a 100 card/min. card punch modified to tie into Cardatron System (can also be used off line).
c) Printer	407 Tabulator (IBM)		a 120 position / line printer with a rate of 150 lines/min. modified to tie into Cardatron System (can also be used off line).
d) Input-Output Control Units (Cardatron System)	(1) 506 Control Unit (ElectroData)		a unit controlling up to a total of 7 input and output units in any combination.
	(1) 507 Input Unit (ElectroData)		a flexible buffer and editing unit on input.
	(2) 509 Output Unit (ElectroData)		a flexible buffer and editing unit on output.
e) Computer	205 Datatron (ElectroData)		an internally programmed electronic computer with a 4000 work storage drum.
f) Tape Control Unit	543 Tape Control Unit (ElectroData)		a unit controlling up to 10 tape reel and bin units in any combination.
g) Tape Storage Reel Unit	544 DataReader (ElectroData)		a bidirectional block (20 word section) addressable tape storage of 400,000 words.
h) Random Access Tape Bin Unit	560 DataFile (ElectroData)		a bidirectional block (20 word section) addressable 50 strip storage of 2,000,000 words.

"THE JOURNAL OF THE INSTITUTE OF METALS"

NIOBIUM

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This reprint consists of two papers presented at a symposium on "The Metallurgy of Niobium," held in London on 1 May 1957. Part I is by Dr. A. B. McIntosh, Head of Culcheth Laboratories, United Kingdom Atomic Energy Authority; Part II is by L. R. Williams of the Research and Development Branch, United Kingdom Atomic Energy Authority, Springfields Laboratory. Reprinted from the April 1957 edition of "The Journal of the Institute of Metals."

I—THE DEVELOPMENT OF NIOBIUM

INTRODUCTION

For use within the fission zone of nuclear reactors which have to work at high temperatures, normal and orthodox engineering materials are unsuitable, either because they absorb too many neutrons or react with the fuel. Because of this, attention has been directed to metals formerly regarded as rare, and great advances have been made in the development of such materials for engineering use.

Among other metals, niobium was selected for investigation, and attention was focused on the economic extraction of the metal from its ores, and on methods of ensuring maximum purity. As a result, niobium has been produced in a more ductile state than ever before, and comprehensive experimental programs to determine the physical and mechanical characteristics of the pure metal and its alloys, necessarily undertaken to develop the use of the metal for atomic-energy purposes, have disclosed it potentialities in other fields.

BASIS OF SELECTION AS A CANNING MATERIAL FOR NUCLEAR REACTORS

The method used by the Industrial Group of the United Kingdom Atomic Energy Authority for the selection of materials for reactors has been surveyed by McIntosh and Bagley.[1] Metallic uranium is sheathed or canned to prevent reaction with the coolant and moderator, and, in addition to possessing specific chemical, physical, mechanical, and nuclear properties, the canning material should be easy to fabricate and join.

Chemical Properties

A canning material must remain compatible with the fuel and coolant under the most rigorous conditions of reactor operation. Theoretical and experimental considerations led to the conclusion that, together with other metals such as tantalum, molybdenum, and tungsten, niobium was suitable as a container for uranium at the required high temperatures, and that it could be used with safety in liquid sodium or sodium-potassium alloy.

Nuclear Properties

The neutron absorption cross-section of any canning material must be as low as possible, because of the effect on neutron economy and consequently on the required degree of enrichment of the fuel. In the handling of radioactive wastes, induced radioactivity resulting from irradiation should be as low as possible. Niobium is, for these reasons, preferable to tantalum, and for use in atomic-energy applications the niobium should have as low a tantalum content as possible. For other engineering applications, this may not be necessary.

Physical Properties

The maximum operating temperature, and consequently the thermal efficiency of a nuclear reactor, are influenced by the melting point of the canning material, which should be as high as possible. Good thermal conductivity is necessary for efficient heat transfer from the fuel to the coolant stream. Any essential alloying needed to obtain enhanced mechanical properties must produce no more than the minimum reduction in thermal conductivity. Preferably, the thermal expansion of the can should be similar to that of the fuel to avoid differential-expansion problems. Finally, especially with gas-cooled reactors, the vapor pressure of the can material at its operating temperature must be sufficiently low to prevent loss of the material to the coolant stream, with possible subsequent deposition in cooler parts of the circuit. Even on the basis of physical properties of material now known to be impure, niobium compared well with other metals in these respects.

Mechanical Properties

The mechanical properties of a canning material should suit the requirements of the particular reactor under consideration. In some reactors it is necessary for the material to restrain the growth of the fuel in a particular direction, and for this purpose it should have high values for yield and ultimate stress, high modulus of elasticity, and high creep strength, together with sufficient ductility to prevent fracture at the operating temperatures and to permit its fabrication into the required can shapes. On the basis of the existing information regarding its compatibility, strength, and other properties, niobium appeared to be a suitable material. The question remained whether fabrication would be difficult if it exhibited the brittle-fracture behavior found in other body-centered cubic metals. Bechtold [2] has shown that tantalum, even though it displays the yield phenomena common to b.c.c. metals, is not subject to brittle fracture in tensile tests at −196° C. Because of their similarity of lattice spacing, position in the Periodic System, and chemical and other properties, it was inferred that niobium and tantalum would probably show similar brittle-fracture behavior.

Program of Development

On these grounds it was considered that niobium would be an important material for reactor use, and work was initiated within the Industrial Group of the United Kingdom Atomic Energy Authority and with suitable industrial firms to determine the best methods of extracting the pure metal, to investigate the effect of impurities and of alloying, to evaluate the physical and mechanical properties, and to develop methods of fabricating the massive metal into the requisite shapes.

THE PRODUCTION METALLURGY OF NIOBIUM

The initial difficulty on embarking on a program of niobium development was to obtain adequate supplies of raw material, owing to the increasing demand for tantalum ores abroad. Niobium was not being produced in Great Britain in 1953, and work was initiated to improve known methods of extraction and to explore alternative and possibly superior means of obtaining the pure metal.

Occurrence

Tantalum and niobium invariably occur together, the principal mineral source of each being an impure niobite-tantalite of iron and manganese of variable composition. This ore is known as tantalite when rich in tantalum, and niobite or columbite when rich in niobium.

The chief source of niobite is Nigeria, where stocks accumulate as by-products from tin-mining. Production increased from 402 tons in 1941 to 2,055 tons in 1944, but fell again to 888 tons in 1949 owing to intensive working of the dumps. Other sources have now been located in Nigeria and the Belgian Congo.[3]

Extraction Development

Differences in the properties and the available thermodynamic data of niobium and tantalum compounds were studied and, taking these factors into account, existing processes for the separation of niobium were reviewed. Difficulties in procuring niobium ore in 1953 led to the use of available ferroniobium for the majority of the extraction processes considered. The details, advantages, and disadvantages of the various methods have been reviewed and the conclusions published elsewhere.[4-6]

THE CHEMICAL PROPERTIES OF NIOBIUM

Oxidation Behavior

At room temperature niobium is resistant to atmospheric corrosion, and samples exposed to the weather in an industrial atmosphere for a period of 15 years have undergone only slight tarnishing.[7] Exposure of niobium sheet in air at 200° C indicated that only temper films were formed, with no oxygen penetration or embrittlement of the metal. The resistance to oxidation by carbon dioxide at 500° C and 8 atmospheres pressure has been determined at Culcheth Laboratories. At this temperature a linear rate law is virtually followed, the loose friable grey scale consisting of the low-temperature modification of Nb_2O_5.

Corrosion by Acidic and Aqueous Media

Niobium possesses excellent corrosion-resistant properties in most acid and aqueous media, owing probably to the existence of a thin oxide layer which protects the underlying metal from attack and renders it passive under most conditions. Only under conditions where the passivity is destroyed by the breakdown of this oxide film does niobium corrode.

The metal has excellent resistance to the common mineral acids over a wide range of concentration and temperature.[8,9] Table I gives the results of laboratory tests carried out on rolled sheet material of high purity. In its resistance to acids, niobium resembles tantalum and titanium, and it is practically unattacked in nitric acid at all concentrations and in dilute hydrochloric acid. It has good resistance to

TABLE I—*Corrosion-Resistance of Niobium in Mineral Acids at 20°–80° C.*[8]

Acid	20° C.	40° C.	60° C.	80° C.
Hydrochloric acid:				
Conc. . .	Excellent	← Good →		Fair
Dil. . .	← Excellent →			
Nitric acid:				
Conc. . .	← Excellent →			
Dil. . .	← Excellent →			
Sulphuric acid:				
Conc. . .	← Fair →			Poor
Dil. . .	← Excellent →			Good

KEY

	Penetration, mm./year
Excellent	< 0.01
Good	0.01-0.1
Fair	0.1 -1.0
Poor	> 1.0

Dilute Acids = 10 vol.-% Concentrated Acids

concentrated hydrochloric acid below 60° C and a fairly good resistance below 80° C (penetration rate 0.24 mm./year at 80° C). In dilute sulphuric acid it again shows excellent resistance, though it is attacked to some extent by the concentrated acid (penetration rate 1.5 mm./year at 80° C). However, even in this severely corrosive environment niobium is probably superior to most other metals, except tantalum and platinum.

Solutions containing the fluoride ion rapidly attack niobium, probably with the formation of complex fluoniobate ions.

Although corrosion-resistance in alkalis has not been investigated so thoroughly, the results of Fontana [9] suggest the resistance of niobium to 5% sodium hydroxide at 100° C (0.5 mm./year penetration) is not good. The metal is probably attacked by caustic alkalis to give solutions containing the niobate ion.

Tests in sodium salts, lactic, acetic, and perchloric acids, 5% phenol, and several acid writing inks have been carried out and no corrosion of niobium whatsoever reported.

Niobium and Liquid Metals

In recent years much interest has been shown in the potentialities of low-melting-point liquid metals for heat transfer. They possess higher heat-transfer coefficients than other fluids and are also suitable for service at high temperatures. These properties make liquid metals attractive for electric power-generation systems, particularly for nuclear-power conversion. The successful exploitation of liquid metals calls for structural materials which are compatible with them under operating conditions. An assessment of the behavior of various metals under these conditions has been made [1] on the basis of their expected or known solubilities or tendencies to compound formation with the liquid metal. Niobium is satisfactory for service with the following pure liquid metals: lithium, sodium, mercury, tin, bismuth, and lead, and also with sodium-potassium alloy. This results from the almost negligible mutua' solubilities of niobium with any of these liquid metals, even at 600° C, and in some cases at higher temperatures.

Because of its current importance for a nuclear-power plant, the greatest amount of attention has been paid to the compatibility of niobium with sodium and with sodium-potassium alloy, which is conveniently liquid at room temperature. Results based on static experiments [8] show that corrosion in either pure liquid metal at 600° C is similar and is less than 0.001 in./year. Similar tests, made at various temperatures between 400° and 600° C with liquid metal of several oxygen contents, have shown that whereas niobium exhibited excellent resistance to the pure liquid metals, the presence of a small concentration of oxygen in the liquid metal caused a significant increase in the corrosion rate. The behavior of niobium in flowing sodium or sodium potassium alloy is largely determined by the oxygen content of the liquid metal, and corrosion may proceed by the formation of a non-adherent scale. This corrosion can, however, be reduced to acceptably low values by ensuring that the oxygen level is kept at a minimum. For this purpose it has been possible to design filters, which depend for their operation on the low solubility of the Na_2O at temperatures just above the melting point of the sodium.

OTHER PROPERTIES OF NIOBIUM

The properties of niobium are discussed in detail by Tottle,[10] but some general properties are listed in Table II to illustrate the wide field of potential applications for this element.

The melting point of niobium exceeds 2000° C and the metal retains its strength to moderately high temperatures, the ultimate tensile strength showing little variation between room temperature and 500° C.

The mechanical properties, especially the ductility, are dependent on the gaseous impurity content, and for good ductility the most exacting control must be exercised over the atmospheres in which any thermal treatments are carried out or in which high-temperature tests are made.

Niobium, in the annealed condition, is both soft and ductile and can readily be drawn, stamped, or forged into complicated shapes. Its rate of work-hardening is much lower than that of most other metals. Niobium can be machined with ordinary steel tools and can be welded by electric spot, seam, butt, and roller processes. Arc welding is difficult, but can be achieved by special techniques.

TABLE II—*Physical and Mechanical Properties of Niobium*

Property	Value	Reference
Atomic number	41	11
Atomic weight	92.91	11
Density at 20° C.	8.66 g./c.c.	8
Crystal structure	Body-centered cubic	11
Lattice constant at 20° C.	3.3004 ± 0.0003 Å.	8, 12
Thermal neutron cross-section (2200 m./sec.)	1.1 barns/atom ± 0.1	13
Melting point	2415° ± 15° C.	11
Mean specific heat at 0° C.	0.0647 cal./g.	7
Magnetic mass susceptibility	$+2.28 \times 10^{-6}$ C.G.S. units	7
Emissivity	0.37 at $\lambda = 6500$ Å.	7
Thermal conductivity (0°—100° C)	0.13 cal./cm. sec. °C.	8
Coefficient of linear expanson (0°—1000° C)	$6.89/°$ C. $\times 10^{-6}$	8
Specfic resistance at 0° C.	15.22 microhm cm.	8
Work-function	4.01 V.	11
Positive-ion emission	5.52 eV.	7
Ultimate tensile strength at 20° C.	17.7 tons/in.^{2}	8
Elongation at 20° C.	49%	8
Hardness	Down to approx. 40 V.P.N.	8

It is a relatively good conductor of heat and electricity, the electrical resistivity being about eight times that of copper; its thermal conductivity (0.13 cal./cm. sec. °C) lies between that of magnesium (0.38) and zirconium (0.04). The work-function of niobium 4.01 V.,[11] is the lowest of any of the pure refractory metals with the exception of hafnium.

The property possessed by niobium of forming a stable oxide under the action of an electric current in acid solution is notable. This film offers low resistance when the niobium is made the negative electrode, but extremely high resistance when the polarity is reversed and the niobium is made positive.[11] The oxide film is thin and tenacious and shows interference colors.

ALLOYS OF NIOBIUM

Alloy Systems

The properties of niobium most likely to promote its use as a structural material are its resistance to corrosion, high melting point, and high-temperature strength. To make the fullest use of these properties, they may require to be further developed, and other properties such as oxidation-resistance, inferior by comparison, may have to be enhanced by suitable alloying. Unfortunately, because of the short history of the metal, very few of the constitutional diagrams are fully known,[14] and even less information exists on the effects of small alloying additions on the mechanical properties and resistance to corrosion and oxidation.

The known binary phase diagrams for niobium alloys (Fig. 1), compiled from various sources, can be supplemented by speculations made on the basis of alloy theory. Such speculations, referring to undetermined systems of interest, are recorded in Table III.

Mechanical Properties

In view of the lack of information on the mechanical properties of niobium alloys, some attempt must be made to assess the most profitable systems for study. While the metallurgical factors determining mechanical properties, and especially creep strength, are not fully understood, some factors are considered favorable to high-temperature strength, such as increased recrystallization temperature, solid-solution hardening, precipitation-hardening, either before or during service, and mechanical hardening by a suitably dispersed stable second phase.

TABLE III—*Niobium Binary Systems for Which no Diagram is Available*

Systems Known to Form Intermetallic Compounds	Systems Likely to Form Intermetallic Compounds	Systems Likely to Exhibit Appreciable Solid Solubility
B	Be	Ag
C	Ru	Al
N	Rh	Au
O	Pd	Cr
Al	Re	Ru
Cr	Os	Rh
Mn	Ir	Pd
	Pt	Hf
		Re
		Os
		Ir
		Pt

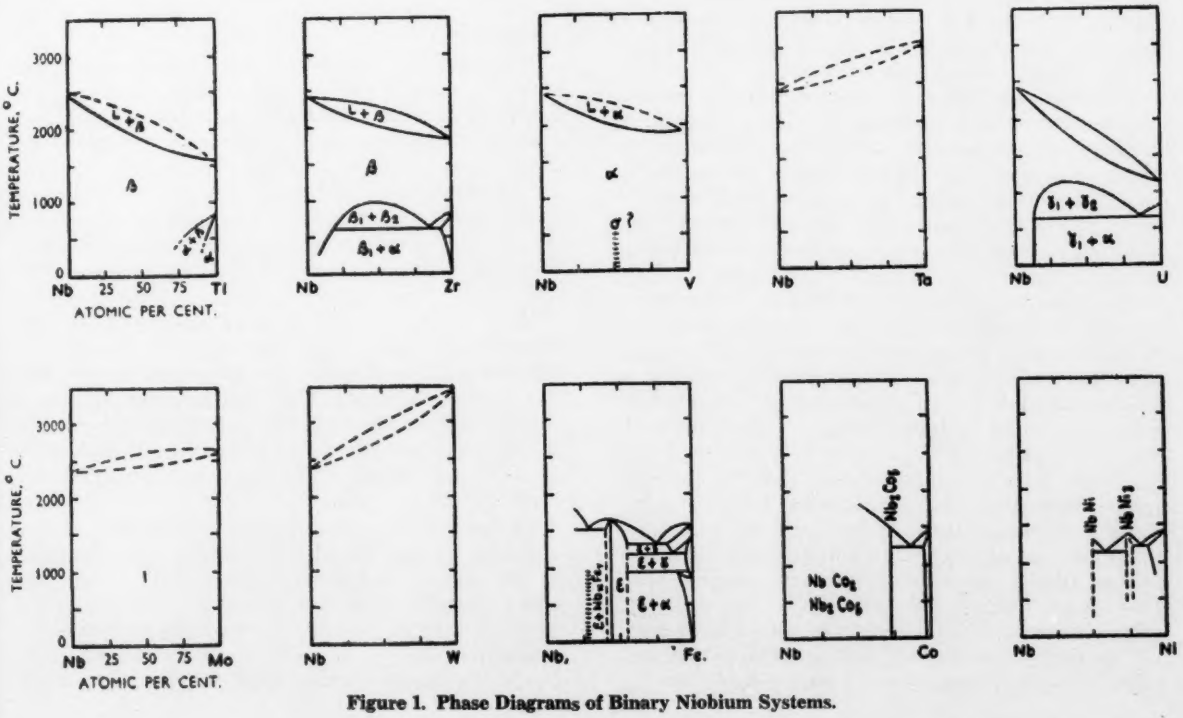


Figure 1. Phase Diagrams of Binary Niobium Systems.

A suitable alloying element for conferring good high-temperature mechanical strength will produce one or more of these effects. Elements which result in alloys of higher melting point may favor increased recrystallization temperature. Alloys with elements of low melting point, such as lithium, magnesium, zinc, cadmium, mercury, and tin, are likely to be difficult to prepare and may be unsuitable beyond a restricted solid-solution range.

With solid solutions, the hardening produced is greater, the greater the distortion of the lattice, and for any system the maximum effect would be expected from a saturated solid solution. Other effects such as segregation to grain boundaries may be helpful, particularly at high temperatures where grain-boundary flow may be the important factor in creep. Thus, suitable elements to produce a high value of solid-solution hardening per unit of addition would be those with borderline size-factors, such as iron, chromium, and nickel. If service conditions allow large-scale alloying, titanium, tantalum, and tungsten may be helpful.

In the development of alloys of other metals, solid-solution effects have frequently not in themselves been sufficient to give high creep-resistance, and recourse must be made to strengthening by precipitation-hardening. Because of their tendency to form intermetallic compounds with niobium, the transition elements of borderline size-factor may prove effective in this way. Iron, for example, has been found to produce age-hardening at elevated temperatures. The requirements of such a precipitation-hardening, creep-resistant alloy are complex. Premature over-aging must be avoided, and general precipitation is preferred to that localized at the grain boundaries. For use over a wide range of temperatures, complex alloys giving hardening effects at different temperatures may be required.

If the rate and nature of the precipitation process may be altered as a result of other factors, such as irradiation, with possible deleterious effects, an alternative is to rely on the stiffening of the matrix by means of a harder second phase, preferably concentrated at the grain boundaries, an effect which may be found in systems with a peritectoid or eutectoid reaction. The second phase must be stable at the operating temperature, particularly with respect to re-solution and softening. In this respect a compound of high melting point may prove useful, and the transition elements are again of interest because of their tendency to form electron compounds, such as have been found in binary alloys of niobium with iron, cobalt, and nickel. Unfortunately, alloys of niobium with other transition metals may be liable to σ-phase formation, and such phases have been reported [15] in binary alloys of niobium with rhenium, ruthenium, palladium, and platinum. The presence of σ-phase usually causes embrittlement coupled with a decline in strength and oxidation-resistance.

Other substitutional elements likely to form compounds with niobium are the electronegative elements arsenic, antimony, and bismuth in Group VB and telurium in Group VIB, which are liable to form compounds of the nickel-arsenide type. These compounds will probably be detrimental in niobium alloys because of their low melting points.

The elements likely to form interstitial solutions and compounds should also be considered. Interstitial solid solutions with niobium are probable for hydrogen, oxygen, nitrogen, and carbon,[16] and possibly boron, beryllium, and silicon. All these elements may show solid-solution hardening, aging, and compound-formation effects; the carbides, borides, nitrides, and silicides of niobium are all hard compounds which are stable up to high melting points. These elements are thus of interest in the development of a creep-resistant alloy. Nitrogen and oxygen have actually been found [8] to have a strengthening effect in niobium, and similar behavior has been found in tantalum-base alloys.

The effects of alloying on mechanical properties, and especially on creep, are, however, likely to be complex; Glen,[17] for example, in work on steels, has shown that the influence of one alloying element depends on others which are present.

Oxidation-Resistance

Niobium shows its group valency in films formed by gaseous oxidation. Examination of oxidation data shows that the best resistance to oxidation is found in metals which form ionic oxide lattices with close packing of both cationic and anionic lattices. Such metals, of which beryllium, aluminum, nickel, and chromium are outstanding examples, have small metal ions, resulting in a minimum oxygen-oxygen distance in the lattice, and a valency of 2 or 3. The cation-cation spacing in the lattice is sufficiently small to give a high activation energy for oxygen diffusion.[18]

Niobium does not show such characteristics, and its oxide has a widely spaced lattice of metal ions at larger interatomic distances than the oxygen ions. Oxides of this type have fairly open structures and show some covalent bonding. They probably grow by an oxygen-ion-diffusion mechanism associated with low activation energy. The activation energy of oxidation of niobium in pure oxygen has been determined as approximately 10 k.cal./g. mole at 500°–800° C.[19]

Much work is required to develop the resistance to oxidation of niobium, and this may be achieved through a study of oxide-film formation on the metal in relation to alloying. Two main approaches may be recommended, although the definition of principles is difficult in view of the linear nature of the scaling in oxidation found by Bridges and Fassell,[19] and confirmed at Culcheth.

Niobium oxide probably grows by oxygen diffusion inwards, so that an alloying solute which diffuses to the surface and preferentially forms a coherent and protective oxide film would prevent the formation of niobium oxide; no evidence, however, is available to aid in the selection of such alloying elements. Extensive sorting tests will be necessary to

establish alloys which form oxide films in which the solute atoms predominate.

In an attempt to modify the structure of niobium oxide, alloys of niobium with elements from Groups IVA, VA, and VIA have been selected for study, and alloys of niobium and zirconium have been shown to be promising.

Naturally it should always be demonstrated that improvement in oxidation-resistance does not necessarily entail deterioration in mechanical properties.

DISCUSSION

In previous sections the reasons have been discussed for the particular interest of niobium to the United Kingdom Atomic Energy Authority, and the properties which may be of value in other industrial uses have been outlined.

Niobium has no unique physical and mechanical properties, but it enjoys a field of application of its own because it has useful combinations of properties that are not possessed by other metals. For example, niobium resists tearing and splitting more than most other metals when subjected to deep-drawing operations.

The available evidence indicates that niobium is a most attractive corrosion-resistant metal which could be employed for handling the strong mineral acids, with the exception of hydrofluoric acid. The low corrosion rates to be expected under most conditions suggest that the metal could be satisfactorily used in thin sheet form as a corrosion-resistant liner to face reaction vessels and thus increase the plant life of items made of cheaper but less resistant alloys. From the point of view of corrosion-resistance alone, niobium does not in general offer any advantages over tantalum, but the large difference in density between the two metals (Nb=8.57, Ta=16.6 g./c.c.) would prove a significant point in favor of niobium in circumstances where the weight of the structure is an important consideration. Equality of cost of the metals would result in economy if niobium were used.

There are many applications, for example in chemical-processing equipment and electrical rectifiers and capacitors, where tantalum is now used, for which niobium would be equally suitable, and in which the use of tantalum has resulted mainly from its earlier availability. The two metals are also both suitable for use as gettering materials in electronic tubes as a result of their oxidation behavior, melting point, high-tempertature strength, and low vapor pressure. Niobium is reported to be the more effective in this respect. Although it does not hold the gaseous impurities up to such a high temperature as does tantalum, less niobium is required than tantalum.

The development of alloys with excellent strength at high temperatures should result from systematic studies of alloying, particularly with iron, cobalt, and nickel, and the interstitial elements, carbon, oxygen, nitrogen, boron, beryllium, and silicon.

Such alloys will be limited in application unless the resistance of niobium to atmospheric corrosion is improved. The approach to this problem may be less systematic, but encouraging results have been shown by the incorporation of alloying elements such as zirconium, which modify the structure of the niobium oxide film formed on the metal. A large field of interesting work arises from a study of the oxidation behavior of such alloys, with and without the addition of interstitial solutes such as beryllium, boron, or silicon, which may also assist in increasing the coherent and protective nature of the oxide film formed.

II—THE PRODUCTION AND FABRICATION OF MASSIVE NIOBIUM METAL

INTRODUCTION

The general consideration leading to a decision to develop niobium as a possible canning material for use in nuclear reactors, and the principles underlying the production of the metal in a massive ductile form, have been dealt with elsewhere.[1,20] The main purpose of the present paper is to give a more detailed account of the application of these principles to the development of production techniques, and to describe the processes for subsequently fabricating the metal to sheet, rod, tubes, and other shapes.

A number of methods have been proposed for the production of the metal, including the electrolysis of fused potassium niobium oxyfluoride, the reduction of the oxide by the carbide,[21] and the reduction of potassium niobium heptafluoniobate by metals such as sodium and magnesium.[6] The reduction of the trichloride by hydrogen and other reductants has also been suggested.[4,5] All these methods yield the metal in powder form, and the two major problems in further processing are to remove deleterious impurities and to convert the powder into massive form.

The two types of processing suitable for the production of massive ductile metal are: (i) melting and (ii) powder-metallurgy methods. In both cases temperatures in excess of 2000° C must be used, and a high standard of vacuum technology is demanded to minimize contamination by traces of oxygen and nitrogen; in addition, provision must be made for exposing as large a surface area as possible in order to expedite the elimination of impurities.

MELTING TECHNIQUES

The use of conventional H.F. melting methods is normally restricted to temperatures of the order of 1700° C. Above this limit, particularly when dealing with reactive metals such as niobium, the refractory problem becomes acute both from the point of view of the high standards of purity required, and the strength of the lining material at operating temperatures. This restricts the possible processes to arc-melting techniques, the two principal variants of which are: (a) the use of non-consumable tungsten or thoriated tungsten electrodes and (b) the use of

consumable electrodes built up of niobium powder pressed into convenient shapes.

If the non-consumable electrode process is used, the metal is liable to suffer contamination from the electrodes. Moreover the need to maintain a small pressure of an inert gas such as argon in order to ensure a stable arc means that the purification process will certainly be retarded, and it may be inhibited altogether. Prolonged treatment in specially designed equipment, in which provision is made for circulating and purifying the inert gas, would be necessary in order to achieve effective purification in a reasonable time.

In the consumable-electrode process, the mass and size of the ingot produced may be varied within wide limits. However, the time interval between melting and solidification is very short, thus providing only limited opportunity for the removal of impurities in gaseous form. The volatilization of impurities, such as oxides of niobium, may not prove effective for their removal, as the vapor will condense on the walls of the water-cooled mold and be partially or completely reabsorbed in the metal as melting proceeds. To achieve a satisfactory result, the carbon and oxygen would have to be present in exactly the right proportions to make possible their removal in gaseous form. Lack of accurate data renders the calculation of the equilibrium pressures of carbon monoxide over the molten metal very uncertain. However, it is possible that the reaction would proceed at the pressures attainable in commercial arc-melting equipment. If such a unit were operated at a chamber pressure of 10^{-2} mm. Hg, the pumping speed required for the removal of 0.3% carbon as carbon monoxide at melting rates of 2 kg./min. would be of the order of 10^{4} l./sec.

The practicability of removing sufficient of the impurities to give a truly ductile product, using either variant of the arc-melting process, has not been established. The method can, however, certainly be applied to the production of large masses by melting niobium rendered ductile by other methods.

Mention may be made at this point of the possibility of employing electron-bombardment techniques for the production of ultra-pure material. This technique has been developed on a laboratory scale at the Culcheth Laboratories of the U.K.A.E.A., and it has been shown that exceptionally high degrees of purity can be achieved. Methods of increasing the scale of operation are at present being investigated.

POWDER-METALLURGY TECHNIQUES

Methods of Heating

The alternative method of processing niobium is by the use of powder-metallurgy techniques, in which the metal is retained in the solid phase. The operating temperatures are rather below the melting point of the metal, and the removal of impurities in both gaseous and vapor form is practicable. The necessary energy for raising the bar to temperature can be supplied by induction or resistance heating (direct or indirect).

The fact that temperatures in excess of 2000° C are required and the need for restricting contamination, particularly by carbon, rules out the use of conventional molybdenum or tungsten cage-type furnaces, and the use of graphite resistors for indirect heating.

Rapid advances are now being made in the development of both apparatus and techniques for high-frequency vacuum sintering. Only motor generators are suitable for supplying the low-voltage input required for operation in high vacuum. The frequencies preferred are of the order of 2-4 kc. and the voltage should not exceed 250 V. in order to minimize difficulties arising from glow discharge. One of the problems associated with the use of induction heating arises from the fact that variations of temperature along the length of the specimen, i.e. along the major axis of the inductor coil, cannot be directly detected. This is probably not of primary importance from the production aspect; provided that the necessary conditions can be established and maintained precisely for each metal or alloy on the basis of experience, the measurement of the top temperature may be adequate as a means of control.

The direct-resistance heating method, in which the source of energy is the passage of an electric current through the specimen, was first developed by Cooldige in 1909 and used for the sintering of molybdenum and tungsten in hydrogen atmospheres. A logical development has been the adaptation of the equipment to permit of vacuum processing. Equipment is commercially available, the design of which is based on many years' operating experience. The method is particularly suitable for development work, as the equipment can be so designed that the bar may be examined visually over its whole length throughout the processing cycle. The use of water-cooled electrodes for gripping the bar has the disadvantage that a temperature gradient is developed at both ends; this may be partially offset by arranging for suitable changes of cross-sectional area, but some discard is inevitable.

Summarizing, it may be said that both induction and resistance heating are practicable for the sintering of niobium using powder-metallurgy methods, and the decision as to the choice of method is dependent on a number of factors, including the availability of equipment and of processing facilities. Arc-melting techniques need further development, but the possibilities of the method improve as the purity of the raw powder increases. Given a sufficiently pure starting material, there is no reason why this method, with its enormous potential output, should not prove to be the most economical, particularly where part of the capacity of an existing unit can be made available.

Power Requirements for Sintering

The power required for sintering is a function of the surface area of the specimen, the temperature required, and the surface emissivity of the specimen, and is approximately 60 kW. for a specimen

24×4×1 in., of surface emissivity 0.4 radiating freely at 2000° C. The use of heat-reflecting screens would reduce this figure considerably. The power required increases linearly with surface emissivity.

In the case of resistance heating, it is essential that the electrical system be designed to supply the power required over a wide range of voltages and current values, as the electrical resistivity decreases by a factor of over 10^3 during sintering (see Fig. 5). The maximum supply voltage will be that necessary to ensure that sufficient amperage can be passed to permit of heating the bars in the "green" condition. The maximum current values are associated with the end of the process, when the bar is in the purest condition at maximum temperature.

The amperage required to maintain rectangular specimens of the same material but of differing widths and thicknesses at the same temperature may be derived to a first approximation from the relationship:

$$I^2 = kwt\ (w + t)$$

where I = current required, w = width of bar, t = thickness of bar and k = constant.

It will be noted that the amperage required is independent of the length of the specimen.

Vacuum Requirements for Sintering

Niobium metal, particularly in powder form, is an excellent "getter," rapidly absorbing both oxygen and nitrogen when heated; in addition, hydrogen is rapidly absorbed at temperatures up to 500° C. All three elements, together with carbon, are present in appreciable amounts in the as-reduced powders.

The elimination of these impurities is vital to the production of the ductile metal, and the successful application of high-vacuum techniques is a major controlling factor at all stages involving processing at elevated temperatures. The vacuum requirements have therefore been considered in some detail, on the assumption that the rates of diffusion of the impurities to exposed surfaces do not constitute the controlling variable for their elimination.

O'Driscoll and Miller [20] have shown that three main purification mechanisms may operate during sintering. First, there is the low-temperature elimination of hydrogen up to 1000° C. This is followed by the formation of carbon monoxide above 1650° C, and, lastly, the elimination of oxygen takes place at temperatures above 1900° C, probably as the result of the volatilization of an oxide of niobium. The vacuum requirements are different for each stage of processing.

The hydrogen released at low temperatures gives the largest gas flow of the whole sintering cycle, and large pumps are required, first, to permit of its rapid removal, and secondly, to return the system to the pressure at which the subsequent stage of purification can proceed. Care must be exercised at the early stages of gas removal to avoid the mechanical disruption of the bar, owing to the build-up of excessive internal pressures of hydrogen. Important factors are the rate of temperature rise, which controls the rate of evolution of gas at the surface of individual particles and the pressing pressure used, and the particle-size distribution of the powder, both of which control the permeability of the compacts. The thickness of the compacts is also important. It should be stressed that cracks or other flaws which develop at this stage are difficult, if not impossible, to eradicate at later stages of processing. The vacuum requirement for this operation is clearly a large volume capacity at a reasonably low pressure.

The next stage of gas evolution is associated with the formation and removal of carbon monoxide. Richardson [22] estimates the equilibrium pressure at 2000° C to be given, within a factor of ten, by:

$$P_{CO}\,(\text{mm. Hg}) = 3 \times 10^{-2}\,(\text{wt.-\%}O_2)\,(\text{wt.-\% C}),$$

from which it may be shown that the partial pressure of carbon monoxide in the system must be maintained below 3.4×10^{-5} mm. Hg to permit of the reduction of both carbon and oxygen to less than 0.03%. The pumping speed required to remove the carbon in a given time can also be calculated and gives a value of 7 l./sec./g. of niobium sintered for a reaction time of 5 hr. The result is, however, of little practical value, as the uncertainty of the thermodynamic data is such that this value could vary be-

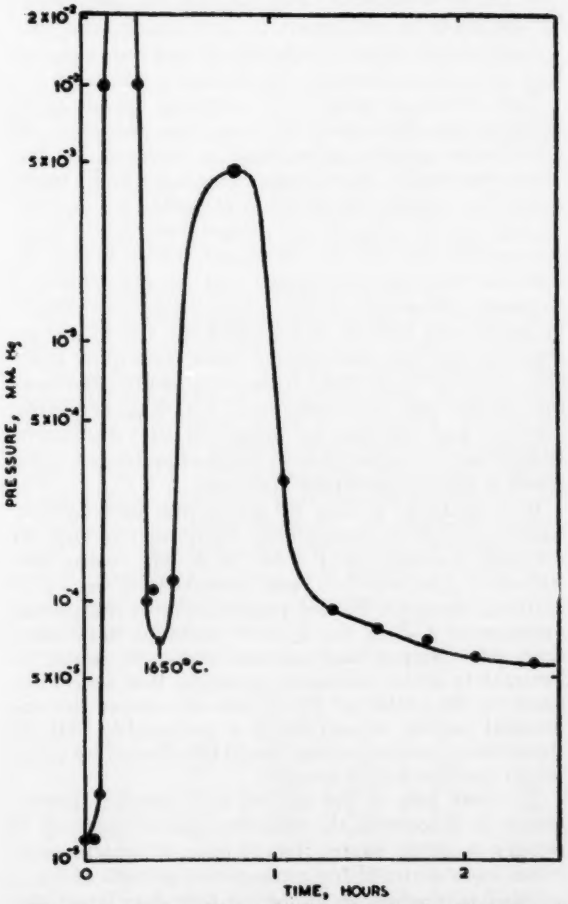


Figure 2. Pressure/Time Relationship for the Sintering of Niobium.

tween 0.7 and 70 l./sec./g. The pumping speed is, therefore, best considered in relation to an actual experimental result. Fig. 2 shows the pressure/time relationship obtained for the sintering of a 2-kg. niobium bar in a system having a rated pumping speed of the order of 6500 l./sec. The rapid increase of pressure following the initial removal of hydrogen will be noted. The second increase of pressure which begins at 1650° C, is associated with the removal of carbon monoxide. The agreement between the calculated and observed values of the partial pressure of CO, at the beginning and end, respectively, of the carbon-monoxide evolution is worthy of comment. The time required to complete the sintering was, in this instance, 6 hr., the bar thickness being 0.9 in.

Little information is available regarding the vacuum requirements for the third reaction, i.e. the elimination of oxide as vapor. Clearly the reaction is primarily dependent on the vapor pressure of the oxide. A lower limit of pressure can be specified on the basis that no increase in reaction rate can be expected when the mean free path in the system exceeds the distance between the specimen and the walls of the chamber, which corresponds to 3×10^{-4} mm. Hg for a distance of 25 cm. Any oxygen "seen" by the niobium will react to form oxide, and this will effectively decrease the rate of oxygen removal; leak rates must therefore be kept to a minimum.

The object of using high pumping speeds is to facilitate the elimination of impurities. However, all oil-diffusion pumps suffer from a tendency for the "back-streaming" of oil vapor. This is normally minimized by introducing systems of baffles which may or may not be refrigerated, depending on the contamination that can be permitted. These baffles reduce the rated pumping speed, and the more effective the baffle, the greater is this effect. This factor should be taken into account in assessing the size of pumps required for any particular system. The same principle applies to all other forms of shielding between the pump and the specimen, e.g. heat-reflecting screens, and the aim in designing the equipment should be to ensure the maximum effective pumping speed at the surface of the specimen.

In conclusion, it may be stated that niobium has been successfully sintered in equipment having an ultimate vacuum of 1×10^{-5} mm. Hg, using oil-diffusion pumps with a rated speed of 3 l./sec./g. of material sintered. Theory predicts that if the partial pressure of CO in the system could be decreased, then the oxygen and carbon contents could be brought to lower values; in practice, this would depend on the ability of the system to remove the additional carbon monoxide at a reasonable rate at these lower pressures and would be effected by using larger pumps than at present.

The leak rate of the system is of primary importance, as it controls the effective rate of removal of oxygen as oxide vapor. Recent tests, in which specimens were sintered for consecutive periods of 2 hr., showed that when an abnormal leak developed, the hardness of the bar after treatment increased from

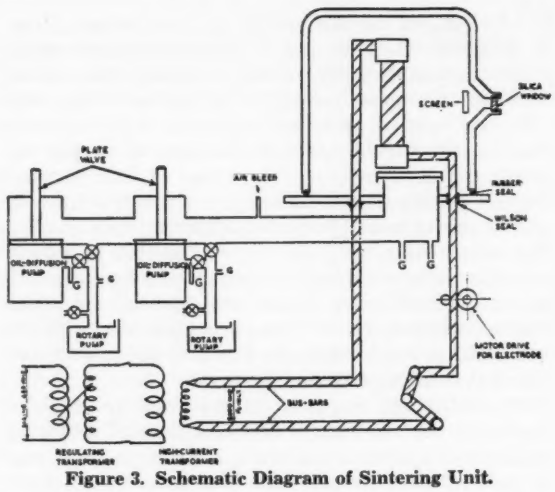


Figure 3. Schematic Diagram of Sintering Unit.

70 to 100 V.P.N. The hardness decreased to its original value after re-treatment under normal conditions.

EQUIPMENT

Sintering Unit

The equipment used for development work at Springfields is of the direct-resistance heating type and is shown schematically in Fig. 3. It consists essentially of a sintering bell, a vacuum-pumping unit, a transformer system, and a suitably integrated control system.

The sintering bell is a double-walled copper chamber, approximately 2 ft. in dia. and 3 ft. high, having two observation ports fitted at right angles to one another, thus enabling both the front face and edge of the bar being sintered to be viewed. Each port is fitted with a mechanism by means of which a number of glass slides or a blank plate can be rotated in turn to cover the inside surface of the window. The base plate is fitted with a central port which connects to the pumping system, and the vacuum seal between the bell and base plate consists of a trapezoidal-section rubber ring. The conductor system supplying current to the bar is mounted on the base plate, and the system is arranged to permit of compensation for shrinkage during sintering. The water-cooling system is divided into five separate circuits for the bell, base plate, upper and lower electrode, and the diffusion pumps, respectively.

The vacuum unit consists of two 14-in. oil-diffusion pumps fitted with water-cooled baffles and having a combined pumping speed (unbaffled) of 6500 l./sec. at 10^{-4} mm. Hg. Each diffusion pump is backed by its own rotary pump, giving two systems which can be operated either together or independently, as may be required. The ultimate pressure attainable in the system is of the order of 1×10^{-5} mm. Hg.

The current for sintering is supplied by a high-current transformer which can be connected to supply either 4000 amp. at 30 V. or 8000 amp. at 15 V. Current control is effected by means of an autoregulating transformer.

Temperature Measurement

The accurate and reproducible measurement of temperature is of particular importance during the later stages of sintering, when the bar is maintained for some hours at a temperature near the melting point of the metal. The instrument used is a disappearing-filament type of optical pyrometer sighted through either of the quartz observation windows. A correction is applied for the absorption of the window.

Two major difficulties have been encountered: first, the recording of temperatures lower than the true values as a result of the deposition of volatiles such as niobium oxide on the inner surface of the observation windows, and, secondly, inaccuracies arising from variations in surface emissivity. The importance of the emissivity correction will be appreciated from the fact that for a true temperature of 2300° C the observed temperature varies from 2220° C for $\varepsilon = 0.75$ to 2020° C for $\varepsilon = 0.35$.

The clouding of the observation windows cannot be completely prevented, but may be minimized by introducing suitable baffles and reducing both the number of observations taken and the time per observation to a minimum.

The emissivity of niobium can be calculated from temperature measurements made in, and immediately adjacent to, a hole having a depth : diameter ratio of 5 : 1 drilled in the specimen before sintering. The spectral emissivity may then be calculated from the relationship:

$$\log_{10} \varepsilon_\lambda = K\left(\frac{1}{T_1} - \frac{1}{T_2}\right),$$

where ε_λ = spectral emissivity for wave-length λ, and T_1 and T_2 are the "hole" and surface temperatures, respectively, measured through a filter restricting the wave-length of light passing to λ. Fig. 4 shows the variation in spectral emissivity ($\lambda = 6500$ Å) for a niobium specimen during the course of an actual sintering operation. The fall in emissivity as sintering progresses should be noted.

PROCESSING TECHNIQUES

Sintering

The first mechanical operation is to prepare the requisite mixture of recirculated and raw powder. The reasons for mixing the two grades will be made clearer later. The mixture is then pressed into bars of square or rectangular section, depending on whether the material is required for rod or sheet. The maximum bar dimensions to which niobium can be sintered depend on the power and current available, and for the equipment being considered are 18 × 2½ × 1 in. Particular care must be taken to ensure that the die design and method of pressing permit the load to be simultaneously released on all faces of the compact, in order to minimize the tendency for lamination to occur. Defects arising from the pressing operation cannot be eradicated during the later stages of processing.

The pressed, or "green" bar, as it is sometimes called, is charged into the sintering unit, the assembly is evacuated, the unit checked for leak rate, and the power switched on. The temperature is raised gradually to 300°–400° C, held for a short time while most of the hydrogen is evolved, and then increased to approximately 2300° C; the total heating time to this temperature is about 40 min. Most of the shrinkage occurs in the temperature range 1600°–2000° C, and must be compensated for by adjustment of the electrode positions. The temperature is then further raised to the final temperature, which is of the order of 2300° C. The selection of the final sintering temperature depends primarily on the bar thickness, because a temperature gradient extends from the outside to the middle of the bar, the temperature of the center being the higher. The sharpness of the gradient increases as the thickness of the work-piece increases and has been estimated to be of the order of 50°–80° C, for a thickness of 0.9 in. Since it is not permissible for melting to occur, the maximum temperature as measured on the outside surface must be decreased as the thickness increases; conversely thinner compacts can be taken to higher overall temperatures. The time at maximum temperature may vary between 2 and 10 hrs., depending on the mass of material being sintered. The bar is then allowed to cool to 200° C before the vacuum is broken.

The next operation is to reduce the thickness of the sintered bar by 25-30%, using a cold-forging technique. The bar is then resintered, and in this condition the temperature may be raised very rapidly to the maximum value of 2300° C; both temperature and time at temperature are dependent on the mass and thickness of the bar being treated.

The ends of the bar are then removed and the material rolled to sheet, or swaged to bar, as required.

Removal of Impurities During Sintering

The work described in this paper has been confined to the results obtained using powder supplied to the U.K.A.E.A. by Murex, Ltd., Rainham. The chemical composition of a number of separate batches of powder is given in Table IV. The principal non-metallic impurities are oxygen, hydrogen, and carbon, with silicon and iron as the main metallic impurities. The true particle-size distribution of the powder, as determined by the electron microscope, is in the range 0.01–5 μ. Normal sedimentometer methods, however, give the range as 1–50 μ presumably on account of aggregation. The powder is stable and stores well.

TABLE IV—*Chemical Composition of Niobium Powder*

Batch No.	Weight-%					
	O_2	N_2	H_2	C	Fe	Si
1	0.47	0.05	0.30	0.28	0.03	0.10
2	0.62	0.03	0.29	0.22	0.03	0.04
3	0.62	0.04	0.34	0.25	0.05	0.09
4	0.67	0.05	0.26	0.31	0.05	0.06
5	0.66	0.08	0.26	0.30	0.05	0.03
6	0.74	0.06	0.27	0.30	0.05	0.05
7	0.77	0.05	0.30	0.23	0.05	0.06
8	0.53	0.04	0.23	0.31	0.05	0.08
9	0.54	0.07	0.22	0.32	0.06	0.04
10	0.25	0.06	0.21	0.30	0.02	0.05

Preliminary sintering tests with the powder proved unsuccessful owing to the formation of blisters, which, on examination, were found to be due to the development of gross internal cavities. These cavities were associated with the development of internal gas pressures, subsequent to the closure of surface voids by sintering.

At the same time, work was proceeding on the development of recirculating techniques based on embrittlement by hydrogen. This gave a relatively coarse grade of powder at one of the intermediate crushing stages. Tests made on this powder showed that a high proportion of open porosity remained after sintering at 2300° C and that the bars were completely free from the tendency to blister even when heated rapidly.

This work forms the basis of the procedure now in use, the aim being to adjust the particle size by mixing the two grades of powder to give the required characteristics. Photomicrographs illustrate the abnormally high degree of porosity remaining after the first sintering treatment.

Table V gives the chemical composition of a number of bars before and after sintering. The hydrogen content is not reported, but was in all cases less than 0.001%. It will be noted that there is relatively little change in the iron values, that the silicon content tends to be rather lower, and that the carbon, oxygen, and nitrogen contents are greatly reduced.

TABLE V—*Change of Chemical Composition of Niobium Powder on Sintering*

Chemical Composition of Powder, wt.-%					Chemical Composition of Sheet, wt.-%				
O_2	N_2	C	Si	Fe	O_2	N_2	C	Si	Fe
0.71	0.09	0.18	0.03	0.04	0.005	0.006	0.001	0.007	0.03
...	...	...	...	...	0.01	0.013	0.015	0.007	0.05
...	...	...	...	...	0.018	0.002	0.02	0.007	0.03

The rapid release of carbon monoxide at 1650° C suggests that the diffusion of both elements in niobium is very rapid at this temperature, and gives added support to the suggestion that the controlling variable for carbon elimination is associated with the pumping speed available at the appropriate pressure.

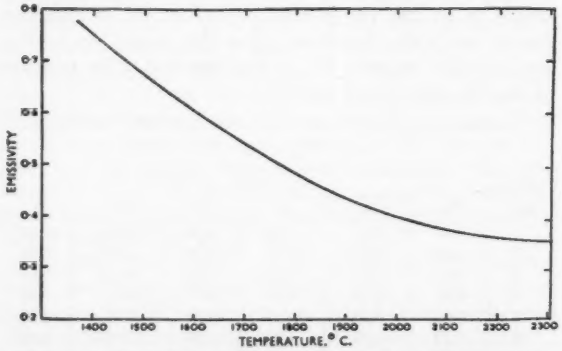


Figure 4. Variation of Spectral Emissivity with Temperature During the Sintering of Niobium Powder Compacts. (λ=6500 Å.)

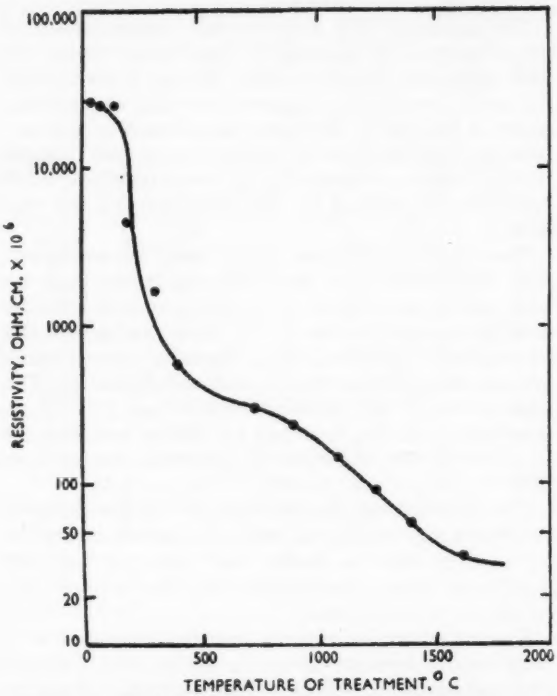


Figure 5. Variation of Resistivity of Niobium Compacts After Heat-Treatment at Temperatures up to 1600° C.

The fact that two mechanisms for oxygen removal operate simulatenously means that the oxygen content of the initial powder must be greater than the stoichiometric amount required for the formation of carbon monoxide, if sufficient is to be retained for removal of carbon. No particular difficulties have been experienced attributable to lack of sufficient oxygen for this purpose, although oxide additions could, of course, easily be made if the sintered bars were found to have high carbon contents.

Physical Changes During Sintering

Not unexpectedly, the resistivity of niobium on sintering drops progressively on heating and has decreased by a factor of 10^3 after heating to 1600° C. The values given in Figure 5 were determined at room temperature after treatment and refer to the original powder as received from Murex, Ltd. The changes in density and modulus of rupture for compacts sintered at temperatures up to 1600° C are shown in Figure 6. It will be noted that the strength of the compact shows a small initial decrease, after which, starting at approximately 350° C, it increases rapidly. This suggests that diffusion processes are operating even at these low temperatures. The density results are rather more erratic at low temperatures, but the trend towards increasing density at temperatures above 900° C is quite clear. Here again, the results refer to the "fine" grade of powder as received from Murex, Ltd. Table VI gives the density of bars processed by the current technique, using a mixture of coarse and fine powder.

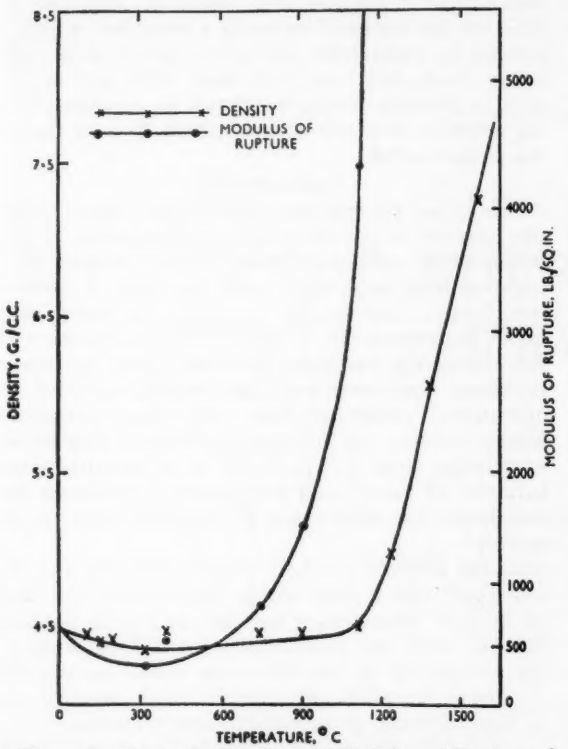


Figure 6. Change in Density and Modulus of Rupture of Cold-Pressed Niobium Compacts Heated for 4 Hr. at Temperatures up to 1600° C.

The hardness of porous bodies, such as sintered bars, does not give an accurate assessment of their mechanical properties, required in this instance for evaluating the success or otherwise of the sintering operation. Hardness tests on sintered bars are thus of very little value and are not generally made. However, the hardness test is of use, as a basis for comparison, for bars in the forged and resintered condition, and values of the order of 120 V.P.N. are normally recorded after a reduction of 25% of the cross-sectional area by cold forging. This figure drops to the range of 60–80 V.P.N. on resintering. Further cold working, such as rolling, results in a steady increase to a value of the order of 160 V.P.N. The relationship between hardness and degree of cold work for fully annealed sheet, is shown in Figure 7.

TABLE VI—*Density Changes in Niobium During Processing from Powder to Sheet*

	Density, g./c.c.
Reported metal density	8.6*
True powder density:	
(a) As-reduced condition	7.9
(b) After recycling	8.4
Bar after pressing at 12 tons/in.²	5.5
After sintering	7.0
After forging	8.2
After resintering	8.3
As sheet	8.6

* As given in ref. 23.

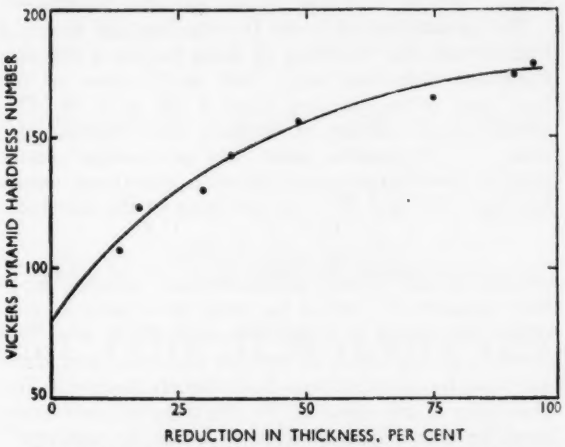


Figure 7. Relationship between Hardness of Niobium and Percentage Reduction in Thickness on Rolling.

Stress Relieving

The nobium sheet, produced as described above, is extremely ductile, and can be rolled directly from sintered bar, say, ½ in. thick, to thin (0.005 in.) strip without any intermediate stress-relieving operations. However, certain mechanical-working operations, of which cupping is a good example, introduce complex stresses which can lead to rapid failure by cracking at the lip of the cup, and it has therefore been necessary to devise suitable methods for stress-relief.

Essentially, the technique consists of heating the sheet to temperatures in the range of 1000°—1250° C in high vacuum, holding at this temperature for some minutes, and then of allowing to cool in vacuum. All the conventional heating methods may be used, but H.F. techniques have a definite advantage, as rapid heating and reasonably short cooling times can be attained. The major factor in the design of suitable equipment is to ensure the lowest leak rate possible. This is particularly the case for shapes which require a number of heat-treatments, as the pick-up of impurities is cumulative. It is normally undesirable, and in most cases impracticable, to re-treat components during fabrication at temperatures sufficiently high to ensure the removal of impurities such as oxygen and nitrogen.

COLD-FORMING OPERATIONS

Sheet and Tube

The ductility of the metal is closely associated with its purity, and it is essential that forming operations shall be carried out entirely in the cold, unless the exclusion of all contaminating gases can be guaranteed during processing.

The following comments are restricted to processes actually used during the past two years and are representative of experience gained, rather than of the inherent formability of the metal.

Sheet can be rolled without difficulty on rolling mills of conventional design. Up to the present time the thinnest strip rolled has been 0.004 in., but there is no reason why foil as thin as 0.001 in. or less

should not be produced, given suitable equipment.

The production of tubes by cupping and drawing begins with the blanking of discs having a suitable thickness : diameter ratio, and work done so far has used ratios varying from 1 : 48 to 1 : 60. The initial stages consist of cupping and drawing the discs on a hydraulic press. The percentage reduction in these cupping and drawing operations varies between 47.5 and 51% on the basis of the formula:

$$\left(\frac{D_b - D_p}{D_b}\right) \times 100,$$

where D_b and D_p are the blank and punch diameters, respectively. When the discs have been manipulated into cups of a suitable size, these are then converted into tubes of smaller diameter and thinner wall by conventional draw-bench methods. The grain-size of the material for the cupping operations must be carefully controlled to avoid "orange-peel" effects.

In the draw-bench operations, single reductions of area up to 35% can be given, with total reductions of 60–80%, before annealing is necessary, the selection of the appropriate point for stress-relieving depending on the thickness : diameter ratio of the tube.

Niobium has a strong tendency to gall when being drawn into tubing and an effective lubricant must be used in order to prevent this occurring. In addition to this the types of material used for tools, i.e., dies and punches, also influence the drawing characteristics. Aluminum bronze, tungsten carbide, and hard chromium-plated tools have been used, aluminum bronze in the main being the most successful.

Rod and Wire

The production of rod and wire follows a similar sequence to that of strip production, except that in this case the starting point is normally square bar, and the rolling operations are replaced by swaging or rod rolling. Techniques for wire drawing have been developed, but difficulties are at present being met with in attempts to use conventional high-speed wire-drawing methods particularly for fine wire, owing again to the "galling" of the wire on to the dies.

Extrusion

Little is so far known regarding the extrusion of niobium. The inherently good formability of the metal suggests, however, that suitable techniques could be developed, if the demand for such products arose.

WELDING

The most important factors affecting the weldability of niobium are its high melting point and its reactivity at elevated temperatures. The basic requirements are thus a high rate of heat input and an inert atmosphere, and the choice of method is limited to resistance welding or modified argon-arc or helium-arc techniques.

Spot-welding methods have been successfully applied, and sound ductile joints produced. Modifications to the normal argon-arc technique are essential to ensure that the argon blanket covers the metal until it has cooled to less than, say, 200° C. This can be achieved by using a container which is purged by evacuation and subsequently filled with argon. Both A.C. and D.C. techniques are applicable, and bright silvery welds can be produced having a tensile strength approximately 85% of that of the parent metal.

CONCLUSIONS

The paper summarizes some of the more important aspects of the sintering and fabrication of niobium, using techniques based on the integration of high-vacuum technology with the arts of powder metallurgy. Considerable progress has been made in an understanding of the relative importance of the numerous variables involved, and the major problems associated with the establishment of an operational procedure have now been overcome. Much, however, still remains to be done. One of the next major steps will probably be to investigate the behavior of alloys, and preliminary indications are that important differences in technique may be required.

As the availability of the metal increases, alternative applications both within and outside the field of nuclear power may emerge, and it is possible that the next few years will see rapid advances in the metallurgy of this, the most recent addition to the group of metals required and used, even though on a small scale, as special-purpose materials.

REFERENCES

1. A. B. McIntosh and K. Q. Bagley, *J. Inst. Metals*, 1955–56, 84, 251.
2. J. H. Bechtold, *Acta Met.*, 1955, 3, 249.
3. ——, *Tin*, 1954, (Feb.), 31.
4. A. B. McIntosh and J. S. Broadley, "Extraction and Refining of the Rarer Metals," p. 272. 1957: London *(Inst. Min. Met.)*.
5. B. R. Steele and D. Geldart, *Ibid.*, 287.
6. G. K. Dickson and J. A. Dukes, *Ibid.*, 258.
7. ——, "Fansteel Columbium" (Data sheet). 1946: North Chicago, Ill. (Fansteel Metallurgical Corporation).
8. Unpublished work carried out in the Culcheth Laboratories of the United Kingdom Atomic Energy Authority.
9. M. G. Fontana, *Indust. Eng. Chem.*, 1952, 44 (7), 71A.
10. C. R. Tottle, *J. Inst. Metals*, 1956–57, 85, (8), 375.
11. C. A. Hampel, "Rare Metals Handbook," p. 394. 1954: New York (Reinhold Publishing Co., Inc.); London (Chapman and Hall, Ltd.).
12. J. W. Edwards, R. Speiser, and H. L. Johnston, *J. Appl. Physics*, 1951, 22, 424.
13. J. Hughes and J. A. Harvey, *U.S. Atomic Energy Commission Publ.*, 1955, (BNL-325).
14. R. H. Myers, *Metallurgia*, 1948, 39, 57.
15. K. Kuo, *Acta Met.*, 1953, 1, 720.
16. C. Ang and C. Wert, *Trans. Amer. Inst. Min. Met. Eng.*, 1953, 197, 1032.
17. J. Glen, *Amer. Soc. Test. Mat., Special Publ.*, No. 128, (1953).
18. R. A. U. Huddle, *Nuclear Eng. and Sci. Congr., Cleveland*, 1955, *Paper No.* 108. To appear in *Trans. Amer. Inst. Min. Met. Eng.*
19. D. W. Bridges and W. M. Fassell, Jr., *J. Electrochem. Soc.*, 1956, 103, 326.
20. W. G. O'Driscoll and G. L. Miller, *Ibid.*, 1956–57, 85, (8), 379.
21. C. W. Balke, *Trans. Electrochem. Soc.*, 1944, 85, 89.
22. F. D. Richardson, private communication.
23. C. J. Smithells, "Metals Reference Book," Vol. II, p. 636. 1955: London (Butterworths Scientific Publications).

LIEUTENANT COMMANDER W. E. MACCOUN, JR., USNR-R

MISSION FOR TOMORROW— SERVICE FOR SUBMARINES

THE AUTHOR

is a professional Naval Architect. He received his B.S. in Naval Architecture from the University of Michigan in 1944. Commissioned through the N.R.O.T.C. upon graduation, he reported to Submarine School and subsequently served in the Submarine Force, Pacific Fleet. He is presently assigned as Repair Officer, Naval Reserve Submarine Division 12-31 of San Francisco, Calif. Lieutenant Commander Maccoun is a member of the Society.

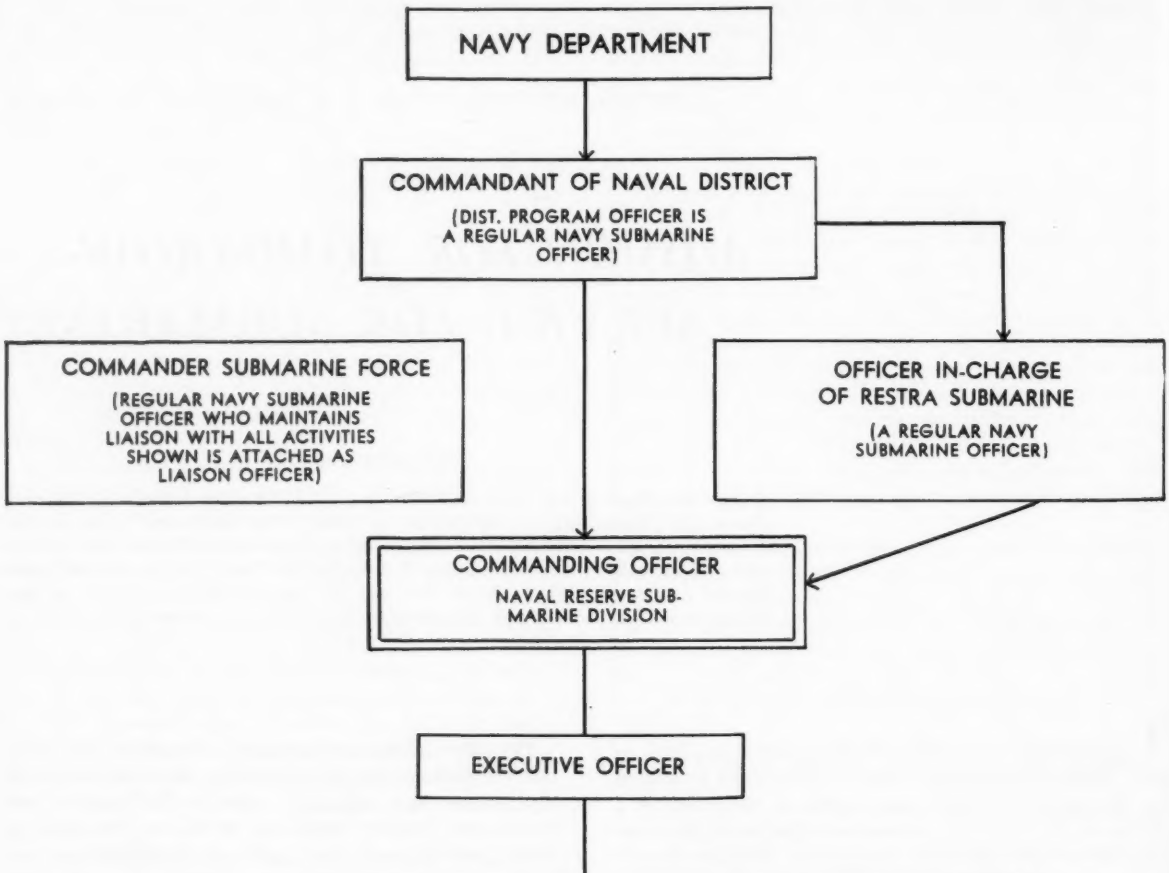
TOMORROW's objective: A competent nucleus of well trained Submarine Repair Reservists available for immediate recall to active duty in the event of a National Emergency; personnel capable of performing duties from getting mothballed submarines underway to repairing submarines at an advanced base.

Today's achievement: A streamlined Submarine Repair Reserve training program that has taken on the New Look.

In this era of critical technical manpower shortages, the Submarine Repair Program has made gains in personnel of over five hundred per cent in the past two years—and the program continues to make these gains with practically no personnel turnover! This somewhat spectacular improvement in the program has been accomplished by simply putting into practice the theory that the value and esprit de corps of any armed forces reserve program can best be improved by making each individual feel that he really belongs to and is a vital part of a military unit with a definite mission. Not only has this recognition of the individual brought positive rewards in manpower, but it has also stimulated a realistic "do it yourself" type of training with immediate returns as opposed to the classroom type of training heretofore employed. Needless to say, it is important to our National Defense that this program be on the right course, for with the advent of the guided missile nuclear submarine any future emergency expansion of the Submarine Force cannot be left to chance.

The Naval Reserve Submarine Program was originally established in April, 1946 by the Chief of Naval Operations and included separate Submarine and Submarine Repair Divisions. Since its inception in 1946, training and organizational modifications and improvements to the program have been made, and in April of 1955 the Submarine Repair Divisions were abolished and consolidated with the Submarine Divisions which now consist of nine officers and one hundred and forty enlisted men, of which two officers and forty enlisted personnel are assigned as members of the Submarine Repair Section. A chart showing the administrative organization of the Repair Section and its command responsibility within the Submarine Division is illustrated on the next page.

In filling the forty available Repair Section billets there are some twenty-seven different eligible "emergency service" ratings to choose from including such ratings as MEW—Metalsmith (Welder), EMP—Electricians Mate (Power) and OM—Optical Man. Since it is conceivable that several one or two man "Divisions" could exist if too fine a line were drawn, the Section has been made composite in nature; and this is reflected in the training program. Men are grouped into the three divisions shown on the chart except that where a few enthusiastic individuals of a particular rating desire to work together "split off" groups such as Ordnance and Electronics, as shown, are encouraged. The composite nature of the Section thus eliminates the almost


NAVY DEPARTMENT
COMMANDANT OF NAVAL DISTRICT
(DIST. PROGRAM OFFICER IS A REGULAR NAVY SUBMARINE OFFICER)
COMMANDER SUBMARINE FORCE
(REGULAR NAVY SUBMARINE OFFICER WHO MAINTAINS LIAISON WITH ALL ACTIVITIES SHOWN IS ATTACHED AS LIAISON OFFICER)
OFFICER IN-CHARGE OF RESTRA SUBMARINE
(A REGULAR NAVY SUBMARINE OFFICER)
COMMANDING OFFICER
NAVAL RESERVE SUB-MARINE DIVISION
EXECUTIVE OFFICER
REPAIR OFFICER
SUBMARINE ATTACK TEAMS (NOT DETAILED)
ASST. REPAIR OFFICER
LEADING C.P.O.
JOB ORDER P.O.
ELECT. DIV. C.P.O.
HULL DIV. C.P.O.
MACHINERY DIV. C.P.O.
ELECTRONICS P.O.
ORDNANCE P.O.

Organizational Chart

impossible task specialized training in each rating would require yet it allows sufficient specialized training for any individual in addition to an opportunity for him to learn something about the other fellow's job.

A further review of the organizational chart reveals the manner in which direction and guidance from within the Navy Department is rendered the Repair Section through the Naval District Commandant. The commanding officer receives assistance in administration, training and recruiting from the Officer-in-Charge of the Reserve Training Submarine, a regular Navy officer attached to the Naval District for a two year tour of duty. He, in turn receives guidance from the Commandant's Submarine Program Coordinator. While both of these submarine officers are assigned to the District a unique situation exists in that unlike other reserve programs they maintain a direct liaison with the Forces Naval Reserve Liaison Officer thus obtaining a special measure of vigor and interest from the ultimate customer of the "product." Therefore, the success and continuation of the program in a particular location, to a large degree depends upon these three highly skilled naval officers who are serving a tour of duty with the reserve component of the Submarine Navy. The Naval Reserve Liaison Officer receives his direction from the Force Commander (either ComSubLant or ComSubPac) being a staff member, while the District Submarine Program Coordinator is tied to the Chief of Naval Operations via the Bureau of Naval Personnel and the Assistant Chief of Naval Operations for Personnel and Reserve Forces. Thus, the Navy Department has provided a highly functional and efficient chain of command and organization procedure to assure a really first class Submarine Repair Program within the framework of any of the twenty-seven submarine divisions scattered throughout the U.S.

The scope of operation and training of the Submarine Repair Reserve has been well defined by the "Manual for Naval Reserve Submarine Repair Sections" which the author assisted in writing. Primarily, this manual presents ideas and material from which a program may be selected for personnel (with or without a prior submarine background) in the techniques and peculiarities of submarine repair. Putting a man to work repairing submarines requires understandings and qualifications not necessary for run of the mill ship repair work—in itself a demanding occupation. Thus, new personnel already proficient in their particular skills need submarine "conditioning." They need to know their way around a "boat," its limited accesses, the multitude of interferences, and the need to work for and with the submariner who first initiated a particular work request. In order to study the operation of the equipment and the personnel and to firmly grasp the fact that a submarine is in effect one well integrated machine, trainees are encouraged to go to sea on short trips. Finally from a technical standpoint prospective submarine repairmen must know the more stringent work standards required such as would be found in testing a hydraulic system or in pressure hull welding. In presenting this training material, the Manual is so designed that courses are not unlike building blocks in that they can be used to form a complete unit in any one of many possible final shapes thus allowing a degree of flexibility. The secondary objective of the Manual is to present topics of special interest such as suggested individual records, which may serve as aids to the smooth administration of a Repair Section. The Manual is intended solely as a guide and not as a substitute for sound planning at a local level.

The new Repair Program, as outlined in the Manual, and pursued here at San Francisco, as in other areas, got underway two years ago with a mere handful of personnel since many of the people in the previous existing Submarine Repair Divisions went to other programs. Therefore, Submarine Divisions were faced with a major task of immediate recruitment of desirable and eligible personnel. Since the program is productive in nature, and in consideration of existing directives, the recruiting was and continues to be geared to mature prior service personnel already skilled in their crafts; men whose civilian occupation is compatible with the reserve effort. This class of citizen-sailor possesses an inherent stability which is an excellent quality since the manpower turnover in the program is thus minimized. Men are attracted to the program for many reasons some of which are: Interest in the military and their fellows, pay (about $24 per week end drill for a Second Class rate), a chance to earn retirement (Average, $65 dollars per month after age 60), interest in learning, keeping up with new developments and certainly patriotism. It should be borne in mind that any man who affiliates himself with a "pay unit" must obligate himself for possible future recall as a member of the "Ready Reserve."

Recruiting originates within the Repair Section itself since the members of the unit believe in it; in truth, the "every man a recruiter" concept pays the most dividends. Our unit has several small groups of men who work in the same shop or trade as civilians. The repair officers themselves must not be adverse to recruiting friends and neighbors.

In addition to this highly personalized means of recruiting, the Repair Sections send letters to certain qualified men in the Inactive Status Pool, follow up with a visit by a two man recruiting team and attempt to spread the word through posters and printed material.

The most important phase of the Repair Program, of course, is that of training using the word training to cover broadly the day by day functional plan. The fundamental concept of the Repair Section training program is that of familiarization with repair of submarines and submarine installations through practical work with a minimum of theoretical study. Although it is not the purpose of the Repair Section to give submarine operational training a degree of submarine familiarization is desirable as has been

noted. In addition to this practical training, opportunity must be afforded for the group to attend advancement-in-rate classes.

Our division at San Franisco meets the first weekend each month for training purposes at the San Francisco Naval Ship Yard Training Center which has shop facilities, classrooms, drill halls and the Naval Reserve Submarine U.S.S. *Dentuda* (SS 334). By meeting on a weekend, each half day is considered a drill day and thus the required four drills per month are covered at once. It is interesting to note that this recently instituted "weekend warrior" routine has proved highly successful from both a recruiting and training standpoint.

Drill for the Repair Section begins when it falls in as a platoon alongside the submarine attack teams at morning quarters. After a brief military drill and an inspection by the Division Commanding Officer; the Repair Officer, who is also the Platoon Officer, reviews the plan of the day, discusses briefly any matters of importance which members bring up and then turns the platoon over to the leading Chief Petty Officer. While the men are still in ranks, the leading C.P.O. passes out job orders (similar to those used throughout the Navy) to the "Division" C.P.O.'s. Thus no man is dismissed from quarters for the day without a definite responsibility to his supervisor. True, he may have certain administrative functions to attend to such as a physical exam, but he is apprised of the day's objective from the start. The job orders in our files vary from the manufacture of life line stanchions to the disassembly of one of the submarine's main engines for inspection purposes. Being a small group with only a limited shop. the Repair Section is treated as a composite unit and a man's rating is not necessarily the determining factor in the assignment of work. The job concept of training is the backbone of the entire program for here each man is singled out, given a definite responsibility and his personal achievement and satisfaction as well as his value to the Navy is a direct function of the quality of workmanship itself.

Basically, Saturday is devoted fully to job order work and at the end of the working day the shop is policed and the men are mustered at final quarters at 1615. Only men with the duty or those from out of town who find it convenient, remain aboard Saturday evening.

With the exception of time out for church, a brief but enthusiastic coffee and doughnut mess in the shop before quarters, the routine for Sunday is much the same as that of Saturday for some members of the unit. However, for others, Sunday is the day which rounds out the program since a good portion of the day is devoted to classroom work. In the morning for about one half hour one of the leading chiefs usually conducts a class (held in the shop since all activities are encouraged to revolve around the shop) on submarine familiarization, which consists of a discussion of a particular unit or system such as the trim and drain manifold. After this class breaks up it is most likely that a small specialized artificer class will be held such as one on "Machine Shop Practices." Personnel not attending this class engage in job order work as is the case with all classes. Inasmuch as most of the repair personnel prefer to participate in job order work, it has proven unwise to insist that personnel attend any particular class with the exception of the "Advancement in Rate Class" which is held Sunday afternoon. Here the composite group of personnel receives instruction which will aid them earn their next rate.

Sunday afternoon quarters, of course, spell the end of Naval Reserve duty for the Repair Section for another month. If the drill weekend has sounded uninspiring to the reader let him be assured that such is far from the case, for interspersed in the routine of the program are such things as talks by visiting highly informed people, trips to sea, tours of new construction, and forays for material, recruiting or planning a Division party, and finally individual expression of personal hopes, fears and doubts.

Our Repair Section personnel are required to take a two weeks tour of active duty every year. The first tour is always to a submarine tender or a submarine rescue vessel. Thereafter personnel may report to an activity activating a submarine, return to a tender, request sea duty or a specialized school.

With the lapse of two years since the program's beginning it is possible to look back at our successes and failures and to project an even better course into tomorrow. When we were attempting to get the Repair Program rolling at San Francisco one of the enlisted members of the then existing group remarked, "How will you get anyone to join, no one wants to be in a reserve program today." Indeed, perhaps some few confused men have felt that the Navy and its Reserve Component represent an unpleasant way of life, or perhaps this might have been the attitude of their family. Indeed you cannot pay a man enough in dollars to join a Reserve Unit. The passage of time, however has positively shown that given a chance to be singled out for the individual that he is, given the opportunity to assume his place in the military chain of command, given the chance to show his ability (the talent which exists in our unit is almost unbelievable) prior-service enlisted personnel are not only receptive to a good program but they will stick with it. Today when a man is recruited by our unit he is told that his attendance must be 100 per cent or he must look elsewhere—we are that sure of ourselves. We feel that in our Repair program we have something valuable and vital to the United States Navy and are constantly refining it to insure its stability and permanence so as to provide good men to the Submarine Force immediately if "battle stations submerged" is sounded again!

COMMANDER BERNARD M. KASSELL, USN

MARINE ENGINEERING NOTES FROM THE SOVIET PRESS

(Biography of the author will be found on page 673)

Atomic Icebreaker

MENTION was made in the May issue of the JOURNAL of Soviet plans for an atomic icebreaker. It now appears that plans have been translated into reality, since we now find that the hull has been named *Lenin* and a photograph of the hull has appeared in at least one Soviet newspaper.

The vessel will reportedly displace 16,000-tons and will develop 44,000-hp. It is under construction in a shipyard in the Leningrad area and is being assembled by block sections into a 134-meter long hull. Each section, according to available reports, weighs between 65 and 75 tons when delivered to the building area for inclusion in the hull. Some idea of the progress being made in construction may be obtained from a brief chronology:

October 1956—Basic hull assembly work in progress.

January 1957—Main drive motors shown in process of construction in shops of the "Elektrosil" Works in Leningrad. Leading designer for the direct current motors A. A. Kashkin. The Kalyzhskaya Turbine Plant announced as builders of vessel's turbines. Incorporated in the turbines are the experiences of leading Soviet turbine designers and builders. Announcement of an original hydro-dynamic system of regulation and the development of a new, economic form of turbine blade. The Moscow Energy Institute imeni Molotov reported to have had a hand in the design. First of the turbines reported as assembled with testing to start soon.

May 1957—Name of vessel officially announced by Moscow radio as *Lenin*.

July 1957—Picture of poor quality showing a hull surrounded by usual scaffolding with caption naming the vessel as the atomic icebreaker *Lenin*. No top hamper in place.

Highly touted of course is the vessel's virtually unlimited cruising radius, with an operational period of one year stated as a minimum before the vessel will have to return to port to refuel.

Whaler Construction Delayed

The 43,800-ton displacement Soviet whaler project appears to have run into difficulties. Whereas it was first reported that the whaler was assigned to the production schedule of the I. I. Nosenko Shipyard in Nikolayev, it now appears that whaling industry specialists have stepped in and taken issue with the original plans to such an extent that the keel, as of mid 1957, had not yet been laid down. Disagreement stems from the fact that the specialists feel the vessel will not be able to process the 65,300-tons of whale and whale oil planned for in the project. The figure has been scaled down to 40,000-tons, including 22,000-tons of oil, as opposed to the projected figure of 48,000-tons of oil. Nor does most recent opinion agree with the contention that the whaler could support 20 catcher vessels. Latest word is that the project will be reworked.

Tanker Construction Continues

According to the Sixth Five-Year Plan directive to the shipbuilders for the maritime fleet, 28 percent of merchant carrying capacity built in the period (1956-1960) is to be tankers. In terms of metric tons of carrying capacity the announced figure is 460,000. Equated to the *Kazbek*-class construction program, the only maritime tanker program known to be in progress in the Soviet Union at the present time, the addition to the tanker fleet would be 46 tankers, or approximately nine units per year. Past performance for the three shipyards engaged in the program, one in the Leningrad area and two, Kherson and Nikolayev, in the Black Sea area, shows a capability to build this number with no difficulty. At the same time there is, apparently, additional capability, as witness one statement that eleven *Kazbeks* would be built in 1957.

Thus, two possibilities exist. First, that the tanker program is slowing down or, second, that another vessel type will absorb the capacity previously alloted to the tanker program. In support of the first possibility is the report that two Soviet tankers *Makhachkala* and *Gorkiy* were, in March 1957, un-

der charter to a British oil company and had, in fact, made at least one delivery to Swansea, Wales. The Soviet offer of vessels for charter is most unusual and when tankers are entered on the charter market the suggestion is that the class is overbuilt and may be in the process of being cut back. At the same time the following item tends to support the second possibility.

Dry-Cargo Ship Program

The same Sixth Five-Year Plan directive which laid down the scope of the tanker building program also provided for a dry-cargo ship program to cover 72 percent of the building effort, or some 1,140,000-tons of carrying capacity. Among the dry-cargo types is the *Dneproges*-class, the lead ship of which class *(Dneproges)* was reported in service in the May JOURNAL. Built in the I. I. Nosenko Shipyard in Nikolayev, she is the forerunner of at least three other sisters, details on which have now become available. This class, so far known to include *Dneproges, Volkhovges, Rionges* and *Kuybyishevges,* are except for the last named, all in service. The class is designed to carry general cargo and loose, bulk cargoes such as grain. Characteristics include:

Length, overall		130.85 meters
Length, between perpendiculars		118.0 meters
Beam		16.8 meters
Height of side		9.5 meters
Draft, full load		7.63 meters
Deadweight at full load draft		7,250 tons
Ship's stores:		
Diesel fuel	655.0 tons	
Boiler fuel	35.0 tons	
Lube oil	46.5 tons	
Boiler water	58.0 tons	
Potable water	53.0 tons	
Displacement, salt water, at full load draft		10,460 tons
Cruising radius		6,000 miles
Speed, designed		16.0 knots

Built on a tanker hull, with engine spaces aft, the class was designed to Rules of the Maritime Register of the USSR, Class UL 4/1 S.

The propulsion installation consists of four diesel-generator units, direct current, Mark 3D100, rated at 1,250-kw each, providing power for the single main drive motor. The diesel engines are two-cycle, 10-cylinder, opposed piston type, rated at 1,800-ehp at 810-rpm. Three auxiliary generators for ship's service are Mark DG-224, rated at 224-kw each. The drive engines are Mark 6Ch23/30, rated at 330-ehp at 750-rpm. All engines, main and auxiliary, are air started.

Each ship is fitted with a four-bladed, cast bronze propeller 5-meters in diameter. A spare propeller, made of stainless steel and with removable blades, is also furnished each vessel.

The following comparative table affords some idea of the increased power being built into the newer vessels:

Name of Vessel	Main Propulsion Characteristics	Power at propeller shaft
Dneproges	Diesel-electric, DC, Mark 3D100, 4 x 1,800-hp., 810-rpm	6,300-hp
Tanker *Apsheron*	Direct drive, Burmeister Wain engine, 5,450-hp., 115-rpm	5,450-hp
Tanker *Volgo-Don*	Diesel-reduction, 8DR-43/61, 2 x 2,000-hp., 250-rpm	3,800-hp

Apsheron is Danish built, while *Volgo-Don* is an early *Kazbek*-class. The *Dneproges* engine installation weight is reported to be 417.8-tons, compared with the *Volgo-Don's* weight of 429-tons, but the significance lies in the fact that the weight-to-horsepower ratio for the *Dneproges* installation is 66.3-kg/hp versus 113-kg/hp for the *Volgo-Don* installation.

New Construction

The imeni S. Ordzhonikidzye Shipyard in Leningrad has been designated as building yard for a large diesel driven refrigerator-trawler. Actually a floating cannery, the vessel will process it own catch. Displacement is given as 3,670-tons and reported speed will be 11-knots. A crew of 100 will man the ship and work its many industrial facilities for processing fish into oil, meal and fillets. This yard has also completed the diesel-electric *Kurgan,* sister of *Akmolinsk* and the third of a series for the fishing industry in the Far East. In production is a 770-ton displacement river icebreaker. The vessel's chief designer, D. A. Syitov, stated that the class, diesel-electric propelled, will be used as tugs during the summer months and as icebreakers in the winter time. A special design in the propeller area, not further explained, will enable the class to break ice of thicknesses in excess of 50-cm.

The Zhdanov Shipyard has started construction of what is called a replenishment vessel, designed to furnish supplies to dredgers and their auxiliaries at the work sites. The vessel is designed to carry 300-tons of coal and 200-tons of fresh water, major commodities for which the dredgers usually secure and come into port. It is expected that the vessel will be able to operate in the open sea in winds up to 30-knots. Hull work is to be completed in November and by the spring of 1958 the vessel is supposed to be operational.

Kazbek-class deliveries since last report include *Slavgorod, Belgorod,* and *Moskovskiy Festival,* all products of the Black Sea shipyards, and *Komsomol,* out of Leningrad. Estimated total number of tankers of the class now operating is 40.

The Sakhalin fishing industry was the recipient of 60 new, self-propelled vessels during the year 1956.

Continuing a practice of many years standing, the shipbuilding organizations in the more industrialized areas of the western USSR have been sending their products by rail to the central areas of the country. In January 1957, for example, pictorial evidence was presented in the press of the arrival in Novosibirsk, on the Ob River, of a group of at least five pusher-

type tugs. These tugs, equipped with diesel propulsion, appear to be of standard type currently in production in the Soviet Union and they were shipped without top hamper such as masts and stacks. In the past the superstructure had been assembled at destination and masts and other rigging added prior to launching.

The Moscow Steamship Line, in 1956, received 120 new vessels and expects, in 1957, to receive over 100 new barges, passenger cutters, steamships, cargo motorships and landing stages.

The Kama Steamship Line has begun to receive the new, improved *Bolshaya Volga*-class cargo motorship of 2,000-tons carrying capacity. The first five such craft, built for the line in the "Krasnoye Sormovo" Shipyard in Gorkiy, were nearing completion in mid year. The new version of this standard river cargo carrier is reported to have a stouter hull than previous models to enable it to operate in light ice. Assembly is done in block sections, four such to a ship, and first reports claimed way time had been cut to 18 days from a former 3 to 4 months. It is further indicated that hull frames, watertight bulkheads, and superstructures are now stamped, an operation claimed as a "first" in the history of Soviet river shipbuilding.

A high-speed river passenger hydrofoil named *Raketa,* built in "Krasnoye Sormovo," was tested this past summer in Gorkiy Roadstead. The vessel is 27-meters long, has a beam of 5-meters and at full speed, a maximum draft of one meter. Trials were reportedly successful, the craft developing 36-knots at full power. Passenger capacity is given as 66 and the one main engine is rated at 750-hp. Built on a duraluminum hull, with superstructure of the same material, the vessel was to have been in service during the recently held Youth Festival in Moscow.

The Novosibirsk Ship Repair Yard, on the Ob River, is planning the construction of repair barges to facilitate the repair and upkeep of river vessels during the season when they operate at points distant from established repair bases. The barges are to be some 80-meters long and 20-meters wide, equipped with an electric plant, shops, machinery, and equipment. Assembly will take place on the yard's slipway and the floating shops will, so far as can be determined, be outfitted locally. The scope of the program is unstated.

France has contributed a turbine driven vessel, *Ilya Mechnikov,* the second of a series of four to be placed in service with the Soviet merchant fleet. Operating for the Black Sea Steamship Company, the vessel by mid year had made several trips to Egypt. Belgium sent the lead ship of a new series of 5,000-ton capacity cargo vessels, *Stanislavskiy,* to the Soviet Union. Initially assigned to the Baltic Steamship Company, more recently she has been operating in the Black Sea area. Sweden, in late 1956, launched an unnamed refrigerator, the fifth of a series for the Soviet Union.

Hungary has been identified as the country in which a series of cargo motorships for the Caspian Steamship Company has been built. Included thus far are *Belogorsk, Tarnopol, Abay Kunanbayev, Shollar, Shongar* and *Pavlik Morozov.* The vessels, in order to reach their destination, had to traverse the Volga-Don Canal, hence certain limitations as to size are apparent, despite the fact that no details have been announced. Their operations thus far put them in the 1,200-ton carrying capacity class.

Communist China is reported to have provided two seagoing passenger vessels, each capable of carrying 80 persons, for use in the Sakhalin area. The two, *Agat* and *Geliotrop,* while called "seagoing," will actually operate in Aniva Gulf in the Korsakov area.

Czechoslovakia continues to provide modern dredges for the USSR. The 16th diesel-electric suction dredge built for the Soviet Union in a Prague shipyard was started on its way and arrived at its destination, the Volga River, late in 1956. The dredge was towed through the river system and the Potsdam Canal to the port of Stettin, Poland. Here the unit was readied for sea and was towed to Leningrad. DE-16, as the dredge has been designated, was then sent from Leningrad via the White Sea-Baltic Canal and the Northern Dvina system to the Volga, finally arriving in Stalingrad. Dredges of this series are reportedly designed to operate in sand, gravel and clay bottoms at depths up to 11-meters on both rivers and lakes. All machinery is electrically operated, with the exception of the spoil pump, which is diesel driven. A central control station, as well as what is referred to as an "automatic control system" is installed. The dredge is fitted with its own repair shop and a considerable amount of machinery and equipment, including a 25-line telephone system. Trials in the Stalingrad area appear to have satisfied the Soviet Trials Committee, which pointed out that the cost of removing a cubic meter of spoil will be less than when dredges of Soviet design, built in the "Krasnoye Sormovo" Shipyard, are used. Certain defects turned up during the trials, however, and the Czech builders agreed to eliminate them in future deliveries.

Lighters for the Caspian Sea, built in East Germany, continue to move down the inland system from Arkhangelsk. The tenth of a series, for use in the Caspian fishing fleet, was reported under tow to its destination. These lighters are rated in the 1,000-ton capacity class.

Holland's DeScheldt Yard in Flushing has built a series of six 6,500-ton displacement refrigerator ships strengthened for operations in ice and diesel-electric propelled. The sixth vessel in the series, *Baykal,* was laid down late in 1956, with nothing further reported.

River Icebreakers

Despite the fact that the Soviet Union is plagued with frozen rivers for many months in the year, only two river icebreakers have been built for the most

important river in the country, the Volga. Named the *Volga* and *Don*, they are products of the "Krasnoye Sormovo" Shipyard where they were completed in 1950. *Volga* has been operating on the reach from Astrakhan to Stalingrad, keeping navigation open until ice formation attains a thickness of 50-cm. Since ice thicknesses of 70-cm are not uncommon, operations are automatically curtailed. At present, because of changed conditions brought about by the construction of the various hydroelectric stations and the formations of their associated reservoirs, additional icebreakers are required. *Volga* and *Don* have certain short-comings which should be eliminated in future designs, according to available information. Deficiencies include inadequate power for all types of ice operations, improper stern shape for breaking ice by use of the stern, and too narrow a beam. The 12-meter beam is inadequate in the face of the need to break ice for tanker barges having beams up to 16-meters.

The 770-ton river icebreaker noted under construction in Leningrad may be the answer to this need.

Maritime Radar

Radar in use on Soviet merchant ships is of a type known as the Neptun, with a second type, Stvor, used mostly on fishing vessels. The chief reported characteristics for the two models are:

Type	Weight, kg	Screen dia, mm	Dead Zone meters	Scales, miles	Bearing Resolution, degrees	Range Resolution, %	Maximum Range, miles
Neptun	800	300	less than 50	1.5, 5, 15, 30	± 2	From 0.6 to 3, depending on distance scale	60
Stvor	230	230	less than 30 (on .5 scale)	0.5, 1, 2.5, 10 and 25	± 2	2	Under 40

The Stvor is a comparatively recent development, the result, apparently of a series of tests made with Neptun fitted on fishing and river vessels, the results of which indicated a need to develop a lightweight set for fishing vessels operating beyond coastal waters. At the same time Stvor was tested during 1956 in many of the river basins and while reported as satisfactory, objection was made for river use to its size and cost. River craft require a light unit with a maximum range of up to 10-kilometers. In the absence of any better unit, however, seven tugs and passenger vessels operating on the Kama River had, by mid 1957, been equipped with the Stvor, evidently modified to provide ranges of from 10 to 15 kilometers.

Reports of new developments in the field of marine radar have been noted. But it is difficult to equate names and descriptions. For example, mention has been made of a new radar with a maximum range of 50 miles, operating in the 3-cm band. Mention has also been made of a Zarnitsa radar, but no details have been uncovered. Soviet objections to their products frequently vary from stated performance, as witness the statement made with regard to the Neptun: ". . . The Neptun, considered to be the best radar in service, has a considerable dead zone, poor resolution in range and bearing, and is heavy . . ." This in the face of the figures presented in the preceding table.

The need for satisfactory radar fitted to Soviet merchant ships is genuine because in eight months of 1956, according to incomplete data, some 1,200 ship-days were lost by these ships because of poor visibility, fog, or other weather conditions which prohibited non-radar equipped vessels from venturing out of port. At the same time 750 ship-days were lost by ships lying-to awaiting favorable conditions to enter ports. The loss of revenue incurred from this idleness amounted to over 19 million rubles. What appear as optimum figures for presently installed radars provide some idea of the navigational capabilities of vessels fitted with the two models in use:

Pickup distance in miles, antenna height 15-meters

	2,000-ton displacement vessel	Large buoy	Spar buoy
Neptun	8-10	2.5	0.7
Stvor	6	1-1.5	0.4

By their own admission, Soviet navigators are not too adept as yet in the use of radar and a recent booklet on use of radar for navigation cautions that

> the use of radar alone for purposes of navigation can, in certain cases, lead to disaster. It is only by the use of all available navigation tools, including radar, as well as by maintaining a constant and accurate plot of the ship's track, that safety at sea can be assured.

Bottom Paints

It is hard for the Soviet innovator, as he is called, to introduce his idea in a shipbuilding or ship repair enterprise which prefers to continue to use a method of work with which it is familiar. Various of the yards in the USSR continue to believe that, when using a new anti-foul paint called Nivk-2, it is necessary to put the ship in the water immediately after the substance is applied. As a specific example we find that the Kanonerskiy Shipyard painted the bottom of the tanker *Pamir*, then undocked her 2 or 3 hours later. Similarly the freighter *Zhan Zhores* was undocked 6 to 7 hours after painting of her hull with anti-foul paint. Evidently Nivk-2 is subject to damage from too long a time in the sun, but at the

same time certain strict procedures must be observed for permitting the paint to dry properly. These procedures are as distinguished from those used with lead and iron oxide paints or Nivk-1. For Nivk-2, drying time is based on the air temperature during painting, as follows:

Air Temperature	Drying Time
20-30 C	18-24 hours
10-20 C	24-36 hours
5-10 C	36-48 hours

Failure to comply with the above requirements results in destruction of the anti-foul paint in a matter of from two to three months.

Fleet Inspection

The Ministry for the Maritime Fleet, in July 1956, started a fleet-wide inspection, the announced purpose of which was to check the technical condition of the ships and to review fuel consumption patterns in an effort to reduce this consumption. Later during the year the emphasis shifted to elimination of machinery derangements, for it was noted that derangement and damage reports continued at the same high level as previously or, as in the case of the Black Sea Steamship Company, increased. Major blame was placed on violations of Sailing Rules and Rules for Technical Operations.

Certain of the derangements came about as a result of failure to observe elementary rules for technical safety in the design and construction of new ships. Diesel tugs equipped with a 3D6 engine, rated at 150-hp, have unusually poor operational qualities. The hull size is so small that when the tug is handling the barges in its caravan, unusual precautions against damage must be taken. Ports and doors in the hull and superstructure are so located that even at slight angles of heel the tugs take water. Design faults have also appeared in the towing gear.

A large passenger type, *Rossiya*, has developed excessive heating in the engine room because engine exhaust piping is of improper size and is improperly run. Compounding factor is inadequate ventilation.

A ferry built in the Astrakhan Shipyard imeni Stalin has poor ventilation in the engine spaces, has no washroom for the crew, no refrigeration installation for the dining room, and no seats on the second deck for the passengers.

In the *Moskvich*-class, a passenger type which has been widely built and in great numbers, it appears that there is no heating system, nor has a boiler been installed, despite the fact that these vessels operate until ice formation precludes continuation.

Three classes of cargo carriers, *Pervomaysk*, *Chulyim* and *Donbass*, are so poorly ventilated in the engine-fireroom spaces that temperatures are excessively high and the air is frequently gas-filled. Living compartments are small and uncomfortable. All three classes are Polish built, but apparently to Soviet design, so the faults in furnace arrangements which cause fireboxes to melt, or the piping arrangements which permit lube oil to enter boiler feed water, are faults of commission on the part of Soviet designers in the post war years. All three types have had "class programs" for reconstruction drawn up which include conversion to oil firing, improvement in ventilation and living spaces, etc., but progress appears to be slow.

Shipbuilding in Poland

As indicated above, Poland has been what appears to be a major contributor to the Soviet merchant fleet. In 1954 it was announced that Gdansk had launched the 100th new merchant ship to unstated account and that the tonnage of ships built in the years immediately preceeding 1954 in shipyards in Gdansk, Gdynia, and Stettin exceeded the entire tonnage of the pre-war Polish merchant fleet. By early 1957 the Polish Minister for Navigation, Professor Stanislav Darskiy, was able to tell press representatives that the Polish merchant fleet consisted of 75 vessels totaling 333,000 displacement tons. Many of these were modern vessels, but many were not. Poland's task was to increase the tonnage of her fleet and, at the same time, to add to it modern. high-speed ships. The Polish 1956-1960 plan include the launching of 32 new merchant ships, of which 12 are in the 10,000 displacement ton class, with the rest of smaller displacements. Just how much of this production is to remain in Polish hands is unknown for at this same time Gdansk was assembling the fourth large vessel in the building program for the Soviet Union. Previous reports had indicated that Poland was planning the construction of tankers of 18,000-tons displacement and that the new plan called for the construction of 270 ocean-going units totaling 750,000 tons, to include, in addition to the tanker, six other types of ships.

Boiler Cleaning

During the general inspection of the technical operations of the fleet some of the crews of dredges and steamships in the Arkhangelsk Sea Route Administration reported a considerable reduction in time spent in cleaning boilers. On the *Robesper*, a wood burner fitted with a span-type, single firebox, firetube boiler with a heating surface of 120 square meters, the chief method used to fight scale formation is treatment of the feed water with boiler compound. The correct combination of blowdown and skillful, regular use of compound has enabled the engine room crew to keep the heating surface clean and this, in turn, has enabled the ship to save 103 cubic meters of firewood in an unstated period of time. In addition, the use of a slime separator has enabled the engineers to reduce the number of surface and bottom blows to two per day, thanks to which the use of boiler feed water has been reduced. Blow down procedures were changed as well. Previously, during blow down 4 to 6 centimeters of water were lost, but this was reduced to from 2 to 4 centimeters. Blow down usually was carried out about one hour after the boiler had been slugged with compound. Compound was added at regularly

set intervals during each watch. These rather elementary engineering procedures were recommended to other crews, and it was further pointed out that the ship, despite the conditions under which it had to operate, was able to go two seasons without cleaning boilers. As a result of the experience of this, and other vessels, the Route Administration has planned a change in the period of time between boiler cleanings to 2,000 hours for steamships and 1,200 hours for all dredges.

New Whale Catchers

Three whale catchers were completed in 1956 in the I. I. Nosenko Shipyard in Nikolayev in time to participate in the 11th SLAVA Whaling Expedition to the Antarctic. *Mirnyiy, Byistriy* and *Komsomolets* are single screw, all-welded and ice strengthened vessels with the following characteristics:

Length	63.6 meters
Length at cargo waterline	59.75 meters
Beam	9.52 meters
Height of side	5.46 meters
Full displacement	1,273 tons
Draft, full load	4.4 meters

The vessels are registered for any ocean, with a seven months cruising duration, capable of independent operation 1,000 miles away from the whaler base. Main propulsion is provided for by four diesel-generator units, Type 5D50, feeding one, twin-armature main-drive motor, Type 2 x PGK-150/65. Machinery is installed in three adjacent compartments. The diesel-generator units were built by the Kharkov Works for Transport Machine Building and each unit consists of a D-50 engine (6-cylinder, 4-cycle, single acting, direct injection, non-reversible, air started) rated at 1,000-hp at 740-rpm. Normal engine life is stated to be 10,000 hours. The generators, built by the Kharkov Works for Diesel Locomotive Electrical Equipment, are direct current, Type MPG 84/44-6, rated at 760-kw, 460 volts, 1,650 amperes, 740-rpm. The main drive motors were built by the Kharkov Electrical-Mechanical Works and are rated at 2 x 1,900-hp (2 x 1,400-kw). One armature voltage is 920 and one armature current is 1,650 amperes. Switching provides for four possible main drive combinations. During trials the vessels made 12.28 knots on one unit, 15.74 on two, 16.9 on three and 17.43 at full power.

Aktyubinsk-Class Refrigerators

This class is virtually identical with the *Dneproges*-class previously reviewed. There are minor differences in ships service generators and, of course, in the refrigeration installation, for this class is a refrigerator transport developed for the Ministry for the Fishing Industry. Thus, the class is rated as capable of carrying 3,700-tons of frozen fish, 4,400-tons of lightly salted fish, or 6,100 tons of fresh fish. The refrigerator spaces have a capacity of 6,850 cubic meters. Each vessel is built of 251 sections in six hull divisions and the ship weighs 1,893-metric tons. The building period is divided into 14 technical stages for planning and accounting purposes as follows:

Stage Name	Number of Stages
Pre-Way	3
Way	6
Fitting out	3
Delivery	2

The six way stages cover a building period of six months per vessel. Trials conducted for the lead ship and a serial ship revealed that sharp cuts had taken place in the total time alloted to this phase of construction:

	Aktyubinsk (Lead) (Apr.-Jul. 56)	*Zelenogradsk* (Serial) (Nov.-Dec. 56)
Moored trials	76 days	32 days
Underway trials	6 days	5 days
Post repair and departure	18 days	10 days
Total	100 days	47 days

Manhours required to build the class were reported to have fallen, percentage wise, from 100 for *Aktyubinsk* to 80.5 for *Akmolinsk* to 71.8 for *Kurgan* to 70.7 for *Zelenogradsk*, with building costs reduced proportionately.

Ship Repair Facilities

The Soviet Union maintains a vast network of ship repair shops, yards and facilities capable of repairing anything from small river craft up to the largest vessels in the merchant fleet at the present time. This same network would, obviously, be available for naval use at any time and hence, whatever shortcomings are apparent in their work reflect directly on both ability to repair and quality of that repair. While many of the facilities are of slight importance, others are equipped with new, modern machinery and equipment. In recent years new slips have been built, dry docks have been constructed and, in areas which do not lend themselves to the construction of dry docks, floating docks have been provided. As a result of such additions, the Soviets now estimate that some 50 percent of the dock work previously done by hand has been mechanized. Hull cleaning and painting, as well as actual hull work, is carried out by mechanized processes of one type or another. Electric welding has replaced the rivet gun, and so on, with the result that labor productivity has risen somewhat, as has the quality of the finished work. This is the broad background to some very spotty performance, however.

For example, the Novosibirsk Ship Repair Yard was equipped with a new slipway in 1955 and is still having trouble in using it efficiently. Critics say there was some excuse for the poor usage of the slipway during the first year of operation because it is, after all, a rather complicated engineering installation requiring trained personnel to handle it. No such personnel were available at the time of installation. Conditions remain the same during the second year of operation, according to a report which castigated the workers for lifting but one barge a day when the schedule called for five per day during the busy season prior to the opening of navigation.

Electric Drive

Passenger vessels of 800-hp operating in unlimited water depths develop speeds of 22-km/hr, whereas when water is limited (a relationship of depth to draft of 1.5) developed speed falls off to 17.5-km/hr. Installations capable of speeds of 27-km/hr in deep water make but 19 in shallow water. These comparisons have led Soviet designers to the conclusion that most effective use can be made of properly designed diesel-electric installations. On the 150-hp *Moskvich*-class, equipped with a 3D6 diesel engine, fuel consumption at middle and low speeds is 15 to 30 percent higher per horsepower than at rated speeds, data which equates equally well to various other types of marine internal combustion engines. Engines designed to yield an average run efficiency of 34 to 36 percent operate at 28 to 29 percent under these shallow water conditions. Tests have shown that for cargo-passenger ships in the Volga basin operating in deep water the most economical speed is 28 to 30-km/hr and in shallow waters (depth to draft of 1.25-1.5) 18 to 20-km/hr. Sea-going diesel-electrics, fitted with four diesel generators are able to make 91 percent of rated speed on three units, 83 percent on two, and 58 percent on one engine operating. This does not appear to be true of diesel-electrics designed for river operation, particularly in the case of the *Volga*-class which is unable to operate at economical speeds because design does not permit using one diesel-generator to feed two motors. In the *Rossiya*-class there are similar restrictions. In addition, the design for the propellers for these two classes was not matched to the power plant driving them and the result has been excessive heating, unused power and reduced efficiency.

The Register of the USSR

The prestige of the Register of the USSR, the only classification society in the country, appears to be at a low level. Engineer V. Shabalov demands a review and/or revision of the rules and norms of the Register. He points out that obsolete and useless requirements of the Register produce negative results in the design, construction and operation of ships. The Register has received hundreds of suggestions for modernization of its rules, but there is no office within the corporate body with responsibility for developing new rules or revising active ones. A Norm Bureau had existed at one time but was liquidated.

Shabalov calls for the establishment of a qualified group with authority to revise and correct the rules and norms and he wants the two Ministers, Merchant Fleet and River Fleet, to assist in this work. The group must be made up of highly qualified personnel who have practical experience.

Equally important in the work of the Register is the Line Inspector Group, but its work is hampered at the present time because no decision has been made as to its subordination. Discussions as to whether the group should be subordinate to the administrative-directorate unit or the production unit have been going on for over a year and a half, yet no decisions have been made. Shabalov states that the inspectors must concern themselves first of all with the quality of the technical inspections they make, not with the money to be derived therefrom and turned over to the State as profit. He doubts that the Register should be considered a profit-making organization at all.

Finally, some decision must be forthcoming to establish the relationship between personnel of the Register and those river steamship lines, ports and organizations which have gone over to local administrations for river transportation as a result of the reorganization in the Ministry for the River Fleet which took place in June, 1956. In the course of this reorganization administrations for river transportation were formed in the Union Republics, each administration becoming subordinate to the individual Council of Ministers for that Republic. There is, thus, a Main Administration for the Dnepr River Steamship Line under the Council of Ministers of the Ukranian SSR. The question posed is where the Register fits into this new organization—a question as yet undecided.

Small-River Craft

Within the framework of the newly formed Ministry for the River Fleet of the Russian Soviet Federated Socialist Republic (RSFSR) is an operational organization known as the Main Administration for River Transportation. This Main Administration, known as GLAVRECHTRANS, is charged with administering the transportation which takes place on what are termed as the "small" rivers in the RSFSR, the largest of the Republics, in which are located some 90 per cent of the total inland navigable water routes in the country. GLAVRECHTRANS is a grouping of 41 local administrations, each of which is responsible for administering the transportation program in a particular basin within the Republic.

The problems arising within the organization are legion, but the two principle problems are (1) obtaining shallow draft vessels and (2) maintaining what little depth there is on many of the routes. For these reasons the organization has cooperated and collaborated with various of the design bureaus to agree on eight basic types of shallow draft, steel self-propelled ships drawing from 40 to 50 centimeters and propelled either by water jet or conventional engines. The same types of propulsion have been used for the cargo motorships designed to carry either 25 or 100 tons of agricultural products.

In addition to the craft mentioned, cargo handling equipment in the form of floating cranes with lift capacities of 750-kg and 1.5-tons have been designed and are under construction.

The usual type of fuel barge, carrying fuel to the farms and the machine tractor stations, is able to carry 40 to 60 tons. These barges are the sole trans-

portation medium for gasoline, kerosene, and lubricants for certain areas of the country and are a vital link in the production chain. At the same time, in order to expand their use, a design for a barge drawing not over 25-cm at full load is badly needed.

GLAVRECHTRANS controls industrial enterprises which include shipyards of various sizes and types. These enterprises were reported to have built 524 new craft in 1956. 154 of these were self-propelled with a total horsepower of 13,700. The 370 non self-propelled craft making up the reported total added 17,000-tons of carrying capacity to the fleet. In addition, 11 suction dredges, each with an hourly capacity of from 45 to 60 cubic meters, were built.

The increase which has taken place in passenger transportation required GLAVRECHTRANS to plan the construction of not less than 50 to 60 passenger cutters for 1957, 25 of which were to be built by yards subordinate to GLAVRECHTRANS, and the remainder to be ordered from other organizations within other Main Administrations and steamship lines.

Innovations

A young engineer from the Gorkiy Institute for Water Transportation Engineers, Ye. B. Shumkov, has designed and built what is called a "magnetic pilot." The unit, said to resemble a "Moskvich" radio receiver, was tested on the passenger diesel-electric *Kazakhstan* on the Volga River. Portable, the instrument can be installed on any ship which has electric steering and a magnetic compass. When tested on the Tsimlyanskiy and Kuybyishev reservoirs the unit, which shifts the rudder automatically to bring the ship to a pre-set course, steered the vessel for five hours and maintained fine control of the set course.

The 25-letiya Oktyabrya Shipyard, on the Volga River, has started the serial production of a new, 300-hp marine diesel engine with six cylinders. The first group of new engines will be used in seagoing passenger ships.

Black Sea seiners are being outfitted with echo sounding equipment which will enable the fishermen to come up with larger catches.

Engineer A. Tereshchenko has worked out an original design for an anchor based on two main cast parts which do not need machining. The anchor's weight is 250-kg. The anchor presently in use in the fleet, the Hall anchor, is made of five parts which require much machine work.

Manufactured in the imeni Parizhskoy Kommunyi Shipyard, the anchor has been successfully tested. Comparative tests with the new anchor opposed to the usual type were made under operational conditions and showed that the new design digs in as well as does the Hall type and has equal holding power. The Trial Committee recommended the new anchor as equipment for installation on maritime ships. According to preliminary estimates, use of the new anchor will bring about an annual saving of over one million rubles, presumably in comparative manufacturing costs.

The autonomy which prevails in river shipbuilding and which, undoubtedly, accounts for many of the difficulties the industry finds itself in, is apparent from a report of a decision, made locally, to convert a lighter on the Yenisey River into a 1,000-ton carrying capacity, 600-hp diesel cargo carrier. Local officials drew the plans and installed two 3D12 engines for main drive. At a cost of 300,000 rubles there was produced an 8-knot cargo ship which can be used under conditions found on open lakes, in river estuaries and along the northern coast of the Soviet Union. The building yard estimated that, including the book value of the lighter, the new vessel was about one-third the cost of a similar vessel obtained on direct order.

The Volga-Don Steamship Line recently undertook experimental work to improve the bite taken by propellers fitted to tugs working for the Line. For various reasons, including shortages of non-ferrous metals, river vesels in the Soviet Union are fitted with steel propellers. The improvement discussed involved the welding to the elliptically shaped blades of the propeller two triangles of 5-mm steel. The idea was to eliminate the terminal losses between the propellers and the directional tunnel in the stern of the vessel. When the modified propellers were tested during dock trials of the experimental tug, a diesel named *Ivan Vazov*, the developed pull was recorded as 9,300-kg as opposed to a previously reported 8,330-kg pull.

Wooden Ships Continue

According to the Chief of the Planning-Economic Administration of the Ministry for the River Fleet of the RSFSR, the cost of operating paddlewheel steamships of wooden construction is 40 per cent higher than the costs for a diesel propelled vessel of the same horsepower. The cost of transporting cargoes in wooden ships, similarly is 25 to 30 per cent higher than the same transport in steel ships. Despite the obvious need to stop building wooden ships and replace them with more economically operated motorships of steel construction, the share of wooden shipbuilding in the 1956 program was, despite some reduction, still on the order of 63 per cent of total tonnage built.

Kazbek-Class Defects

In addition to previously reported faults, the *Kazbek*-class now is found to be lacking adequate insulation against excessive heat and noise. Installed ventilation blowers have "little effect" in ridding compartments and living spaces of the heat.

The vessels are not equipped with explosion-proof blowers to provide the air to protective masks worn during work in areas containing gases when tanks are being cleaned, according to a Trade Union Chairman, N. Bakurskiy. He notes that the Black

Sea Steamship Company, operator of the tankers, has taken only preliminary steps to mechanize tank cleaning. Besides the lack of blowers, the tankers also lack gas analyzers needed to determine the explosiveness of the gaseous mixtures remaining in the tanks. Newly built tankers fare no better than older ones. Neither the Ministry for the Maritime Fleet nor the steamship company have published rules for technical safety during washing, cleaning and de-gassing tanks.

Education

After the XXth Congress of the Communist Party had complained about shortcomings in the training of technicians, the Collegium of the Ministry for the Maritime Fleet held a special session, out of which emerged a decision to form a commission authorized to draw up a new curriculum.

This commission, operating under the Main Administration for Educational Institutions of the Ministry, paid particular attention to studies concerned with electrical and radio-navigation equipment. The findings were that while 199 hours were devoted to studies in this field, comparatively few of those hours were devoted to the theory of the workings of the equipments. As a result 220 hours are now assigned to courses dealing with basic electricity and basic radio. 110 hours are devoted to two courses, one titled "Electrical Navigation Instruments," the other "Radio Navigation Instruments."

Complaints had been made that 185 hours devoted to the study of the English langauge were not enough. The knowledge gained was insufficient to cope with the use of English-language navigation installations, to carry on necessary conversations over radio circuits or on work assignments. The new curriculum assigns 278 hours of compulsory study to English, with 76 optional hours assigned as desired. English will be taught over the entire school period and the study load per semester will be not less than four hours.

In sum, the new curriculum calls for 79 weeks of theoretical study and 66 weeks of practical work, to be undertaken by graduates of the 10-year schools.

Naval Building

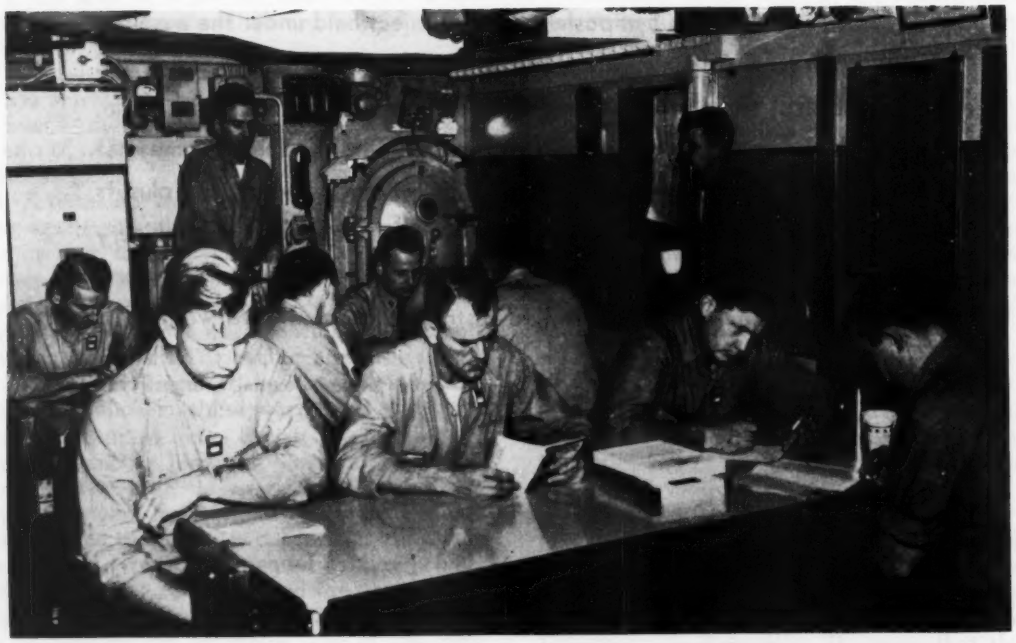
A rare mention of naval building occurred recently when it was announced that the naval building program during the Sixth Five-Year Plan period would "include the construction of warships, auxiliary transports, technical vessels, and ships with special designators."

The proposed nuclear-powered cargo ship now in the design stages was discussed in detail at a Symposium on the subject held under the auspices of the Maritime Administration. The ship will be a passenger-cargo type. It is divided by transverse bulkheads into seven cargo holds, an engine room, a reactor compartment, and the two peak spaces. The ship is somewhat larger than a Mariner type. The length of its reactor compartment plus its engine room is 115 feet, as contrasted to a 70 ft. length for the machinery box of a Mariner. The weight of its plant, including foundations, supports and additional hull steel required to distribute concentrated weights, is estimated to be 1030 tons.

—from "Marine Journal," August 1957

Figure 1 (left). Men in maneuvering room with all eyes focused on the three power panels that supply the power for the USS *Nautilus* (SS 571) during training operations at sea.
—Official U.S. Navy Photograph

Figure 2 (below). Men in large mess hall on off duty hours aboard the USS *Nautilus* (SSN 571) which affords plenty of room for off duty activities. Tables change to seats for movie.
—Official U.S. Navy Photograph



LIEUTENANT BURTON I. EDELSON, USN

SCIENCE AND SCIENTISTS IN THE NAVY

THE AUTHOR

graduated from U. S. Naval Academy in June 1947. Attended U. S. Naval Post-Graduate Schools in Annapolis and Monterery, Calif. in 1951–52 in Mechanical Engineering. Selected for ONR advanced Science course and attended Yale University. Received M.S. in Metallurgy from Yale 1954. Masters' Thesis: "Torsional Relaxation of Polycrystalline Cadmium as a Function of Surface Phenomena." He is now doing research for his doctorate thesis in Metallurgy at Case Institute of Technology, Cleveland, Ohio. Upon receiving his commission he spent four years with the Pacific Fleet first on Destroyers, then as executive officer of a mine sweeper, and finally on CINCPACFLT staff before going to P. G. School After P. G. School was selected as Engineering Duty Officer and was assigned as Electronics Officer on the staff of COMSERVRON TWO. Now serving as Planning Officer, Office of the Resident Supervisor of Shipbuilding, Cleveland, Ohio. Is a member of American Institute of Mining and Metallurgical Engineers, American Society for Metals, and U. S. Naval Institute.

At the Office of Naval Research in Washington, a scientist is perfecting a new missile to fly at the speed of light. At the adjoining desk, a second scientist is busy inventing a faster kind of light. This story may be a bit exaggerated, but the jest serves to point up the greatly accelerated tempo of today's scientific research and its integration into the naval service.

During peacetime, the purpose of the Navy is to prepare for war. This we do by (1) training personnel to use the weapons we have more effectively, and (2) creating better weapons. To create these weapons, we have an organization for research and development—or simply R&D, as it is termed in the Navy, with our penchant for abbreviations.

At the outset, I should like to differentiate between the terms research and development. Research is the primary phase—briefly, the acquisition of knowledge; whereas, development is the application of this knowledge to create products, which are for use: ships and planes, missiles, guns, computers and all other weapons of naval warfare. The need for development of new weapons is obvious and, indeed, development has long been an integral part of our Navy. It is the purpose of this article to set forth the growing importance of both basic and applied research in the military organization, and to suggest means for implementing the effectiveness of our research organization.

Why is scientific research needed? Dr. M. W. Rosen, technical director of Project VANGUARD (the Earth Satellite program) explained this need very succinctly. "It is," he stated, "because the engineers have caught up with the scientists and have almost exhausted our store of basic knowledge. The time lag between discovery of a new material, technique, or principle and its utilization has become increasingly short. The public has come to expect a constant flow of products, each more wonderful than its predecessor. But the engineer, who has always drawn his ingredients from the cupboard of basic research, now finds that the cupboard is bare. He must wait for new ingredients." Scientific research supplies these ingredients.

World War II may be cited as the entry point for a real research organization into the Armed Forces. It was during this crucial period that a rapid expansion of the military research and development program brought a great need for scientists into the military picture. Such laboratory curiosities as microwave interferences and nuclear fission became the hard realities of radar and the atomic bomb, not in generations but in months. An army of scientists in white laboratory coats and in uniforms became a part of the military organization. They served in such wartime organizations as the NDRC and OSRD.* Upon V-J Day, most of these men returned immediately to industrial or academic pursuits.

* National Defense Research Committee and Office of Scientific Research and Development.

R&D CLASSIFICATIONS

NATIONAL SCIENCE FOUNDATION DEFINITIONS:

Basic Research

That type of research which is directed toward the increase of knowledge in science.

Applied Research

That type of research which is directed toward practical application of science.

Development

The systematic use of scientific knowledge directed toward the production of useful materials, devices, systems, or processes other than design and production engineering.

Official U. S. Navy Photograph

Navy's New 600 Inch Radio Telescope Built at Naval Research Laboratory, Washington, D.C. Telescope assembled and placed at horizontal position.

For a short period, only a skeleton of the awesome military scientific organization was left, with very little direction. Then in 1946, the U. S. Navy was the first of all Government agencies to recognize its responsibility for the continuance of a research program, and the need for a vehicle to carry it along. Thus, in that year, by Public Law 588 the Office of Naval Research was established" . . . to plan, foster and encourage scientific research in recognition of its paramount importance as related to the maintenance of naval power and the preservation of national security; [and] to provide within the Department of the Navy a single office which, by contract and otherwise, shall be able to obtain, coordinate and make available to all the bureaus and activities of the Department of the Navy, worldwide scientific information and the necessary services for conducting specialized and imaginative research. . . ." Since the founding of ONR, the National Science Foundation, the Atomic Energy Commission and the other military departments all established parallel research programs.

Today ONR is still a unique and very potent factor in American science. Its central office is located in the shadow of the Washington Monument with branch offices in Boston, New York, Chicago, San Francisco, Pasadena and London. Its directly supervised field activities are the Naval Research Laboratory, Naval Biological Laboratory, Underwater Sound Reference Laboratory and the Special Devices Center. A large part of the basic research is carried out by contract with universities and other laboratories, including non-profit, commercial and Government establishments. Other functions of ONR, too numerous to mention, include applied as well as basic science, and such ancillary functions as regulating Navy patents, sponsoring professional symposia, and organizing the Research Reserve, a large naval reserve group composed exclusively of civilian scientists. I believe it is safe to say that, through its contract and other programs, ONR is much better known in research laboratories and graduate schools throughout the country than it is in the rest of the Navy!

A glimpse at its personnel and budget figures will reveal the magnitude of the organization. ONR and its field activities employ the services of some 200 officers and 4,500 civilian personnel. The 1957 budget for basic research under contract alone is eleven million dollars; the total ONR budget, 56 million; and the overall Navy R&D allocation, 500 million—some 5% of the total Navy budget!

The need for an organization such as ONR is indisputable today. The overriding technological nature of naval warfare includes every phase of research and development. Even a cursory review of progress in modern materials will reveal a radical telescoping of the timetable for all research and development processes, from the test tube to the kitchen, from the phase diagram to the firing line. Compare for a moment the development of the new wonder metal, titanium, with our common friend aluminum, the latter by no means hoary with age. Dr. B. S. Mesick, a retired colonel and MIT Graduate, has recently written, "In less than a decade, metallic titanium

has been developed from a laboratory curiosity to become a basic industry, vital to the defense of our country, even though its potential growth is just beginning. Such rapid development of an industry for the production of new metal—about three times as fast as aluminum—is phenomenal and would not have taken place without the support of hundreds of research and development projects sponsored by the Armed Forces." More recently, the crash program directed by Admiral Rickover for use of metallic zirconium in nuclear reactors took even less time!

The rate of progress of modern-development programs has forced all the Armed Services to take an active interest in the basic sciences. They can no longer wait for others to develop and then merely adapt their ideas to military purposes. In fact, Rear Admiral Rawson Bennet, Chief of Naval Research, wrote for the *Journal of the American Society of Naval Engineers*, "The rate at which these advances are being made is constantly accelerating. The time elapsing between the birth of a scientific concept and the critical experiment is no longer a matter of years. It may be as little as a week. This acceleration has forced the Navy to become deeply involved in science. We cannot merely be a spectator, standing by to purchase any results that look good to us. The Navy must actually be in science, conducting its own work and supporting the work of others."

If the Navy were an industrial concern, a cogent argument for the need for research is to be had from a calculation by Raymond Ewell of the National Science Foundation. He tried to answer the question: How much does society get back, in terms of dollars and cents, for its investment in research? His astonishing answer: 100 to 200 per cent *a year* for the past 25 years! In other words, society has got back $2,500 to $5,000 for every $100 invested in research and development. In the Armed Forces a monetary profit can be interpreted as a more effective use of the taxpayer's dollar and a stronger defense of our country.

But science infers scientists; and development infers engineers. It is no secret today that industry is crying for technical graduates. A casual reader of *The New York Times* financial section literally can find pages of expensive multi-column advertisements imploring scientists and engineers to come to work "in a challenging new field," 'in Sunny California" and with professional advancement, retirement benefits and all-expense cross-country interviews. The United States does not have nearly enough college trained scientific and technical graduates, and the prospects for improvement are not heartening.

A great deal of concern has been created by recent comparisons between this situation in the United States and that in Soviet Russia. The Joint Committee on Atomic Energy just completed a review of the entire problem with truly alarming results. A brief summary (see table below) shows that the total of all technical graduates in Soviet Russia exceeds that of the U. S. by 35% and that their rate of production is twice that of ours.

	U.S.	USSR
Graduate Scientists	225,000	160,000
Graduate Engineers	535,000	730,000
Total Graduates	760,000	890,000
New Graduates, 1954 scientists	31,000	50,000
New Graduates, 1954 engineers	22,000	53,000
Total new graduates	53,000	103,000

"As it stands," John R. Dunning, Dean of Engineering of Columbia University lamented, "nothing can be done to prevent the Russians from gaining on us in scientific and technical manpower at a ratio of 2 to 1. Already we have lost the battle of engineering manpower—at least in numbers."

These figures indicate the essentially unhealthy technical manpower situation for our country as a whole. The problem, if it is to be licked, must be a joint one for industry, educational institutions and the taxpayer. But how is the Defense Department and particularly the naval establishment affected in this regard? The Navy is employer to a tremendous number of technical personnel, some military, many more civilians. It has felt the pinch in both categories.

Speaking, for the moment, only of the officer situation; it has been distinctly difficult to train and retain enough technical officers in the regular Navy, especially in light of the stiff competition from industry for technical manpower.

In the past, thankfully, the U. S. Navy has not had to depend solely on procurement from outside sources for its officer-engineers. There has been a program of long standing in effect for the graduate training of its own. The Naval Postgraduate School in Monterey and several civilian universities have turned out many hundreds of engineers with graduate degrees in most branches of engineering. The technical bureaus and their field activities are staffed with these

Official U. S. Navy Photograph

Atoms for peace. Richard C. Knoebel, Hospital Corpsman First Class, Selinsgrove, Pennsylvania, inserts a specimen into the counting chamber of Alpha Scintillation counter in the Radioisotope Laboratory, National Naval Medical Center, Bethesda, Maryland. Knoebel wears the K-type film badge, on his right wrist, to detect personal radiation.

officers, some of whom have made extensive contributions to their respective professional fields of engineering as well as to the naval service.

There is not now such a strong program for scientific training in the Navy, although a critical need exists today and will, if anything, increase tomorrow. The vast majority of scientists engaged in research and research administration are, and always should be, Civil Service employees. There exists, however, a real need for a greatly increased cadre of regular officers—individuals with a certain breadth of Navy experience who still talk the esoteric language of the scientist and who understand his problems, his methods and his milieu—to serve in supervisory and administrative billets and to give a proper impetus and balance to the Navy's research program.

A good start, but a small one, has been made in a graduate training course for officers in scientific fields. ONR has sponsored, since 1947, an Advance Science postgraduate training curriculum. A small group of officers, not more than 5, are selected for this course each year to study in the fields of chemistry, nuclear and general physics, applied mathematics and metallurgy. These officers spend three or four years at various universities, receiving Master's or Doctor's degrees in their specialties. Under present officer distribution programs, graduates receive duty assignments in ONR billets only during their subsequent regular shore duty assignments. Some have become ED officers and rotate between BuShips and ONR duties. There are now some 40 graduates of the Advanced Science course, of whom about one-fourth are ED's. In addition to these graduates there are other specialists in the Navy who might rightfully qualify to do work in basic science. These are graduates of the advanced nuclear course, other special Bureau sponsored courses, and those physicists, chemists and other science degree holders from the NROTC program.

Exemplary as this program is, it does not satisfy the demands of today and will not begin to meet the requirements envisaged a few years hence. Research is a snowball making ever increasing demands upon itself for men, money and materials. Basic new knowledge is acquired and used at a constantly accelerating rate to establish new products and services, and, in the words of Mr. George F. Metcalf in a detailed report to the American Ordnance Association, thus "it follows that the weapons of the next decade will be born from technology unsuspected and unknown today."

And yet, a scientist does not spring full blown. The accent today is on increased formal training. Where several decades ago a student was at the very frontiers of knowledge upon graduation from high school it now takes four years of college just to know what has been fully digested into textbooks, and years of graduate training to reach the point of individual contribution. We must start a program today to produce scientists six, eight and ten years in the future.

To establish a program for training and employment of naval officers, certain traditional concepts cannot be ignored. One must not get carried away into forgetting that this is a military establishment with certain requirements, both traditional and legal, above and beyond that of mere technical competence. On the other hand, tradition alone is not proof against progress. Certain Congressional laws curtailing the number and designations of specialists can bear changing, as they have in the past. Such problems as incentive pay and rank structure for technical specialists in the Armed Services are even now being looked into by a top-drawer Defense Department committee. There is a good possibility that a new Assistant Secretary of the Navy will be appointed for R&D. All these considerations are relevant to the question of the increasing need for scientific specialization and the problems that must be solved enroute. The immediate goals are these: (1) To substantially increase the procurement and training of officer-scientists; and (2) to insure that these scientists are judiciously employed.

The first of these goals is a question of numbers. The exact number of scientists—that is physicists, chemists, mathematicians, etc.—needed is difficult to estimate, both because of the difficulty in defining what is a scientist, and in the requirements of certain positions. It is very hard to ascertain, for ex-

Official U. S. Navy Photograph

Lieutenant Theodore G. Balbus, a staff medical officer of the Radioisotope Clinical Laboratory, The National Naval Medical Center, Bethesda, Md., operates a Scintigraphic instrument. This produces a line drawing of radioisotope accumulation in the body. Thus certain pathologic conditions in which isotopes accumulate can be charted and anatomically located.

Official U. S. Navy Photograph

Howard L. Vess makes the final inspection of electron tubes before they are turned over to scientists. The tube in the lower right foreground is a radio-frequency spectrometer.

ample, the proportion of electronics experts who should be microwave physicists or electronic engineers. Which job should have the solid state physicist and which the metallurgical engineer? Individual qualifications vary as well as job descriptions. In American industry as a whole, however, the ratio of scientists to engineers employed is about one-fourth. This is probably too high for the Navy. A more reasonable figure would be about one-tenth. This would mean a total of from 100 to 200 scientists. A similar figure is arrived at by totalling the billets which, right now, could be most aptly filled by scientists if the personnel were available. These would include certain billets in the technical bureaus, ONR and its branch offices, and research laboratories of all sorts, such as the Naval Research Laboratory in Anacostia, the Naval Ordnance Laboratory in White Oaks, the Naval Electronics Laboratory in San Diego, Radiological Defense Laboratory in San Francisco, and others. There would, in other words, be many ready-made billets to be filled as well as the new ones bound to open with the Navy's increased participation in science.

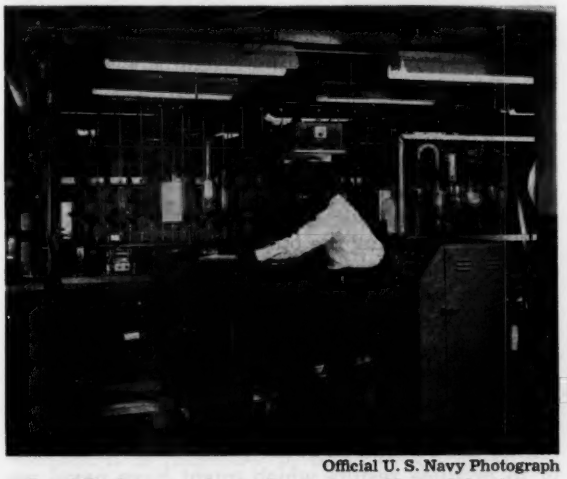
The methods of training need not be changed, although it may not be sufficient to supply all the scientists required. The Advanced Science curriculum, and other graduate programs mentioned above, represent very enlightened thinking on the part of the sponsoring agencies. Only a broadening of the program would be required. This might be supplemented by increased procurement of college graduates direct from civilian life. Direct commissioning of young Ph.D. scientists would be a valuable asset, even if only a small percentage were retained in the regular Navy. It should be pointed out that where Armed Service pay is not competitive with that of industry, or in the case of physicians with private practice, it is so with academic positions. I have personally known several Ph.D's with service obligations who were drafted into the Army when the Navy had no commission to offer.

Once trained personnel are available, their judicious employment becomes essential. What is needed is a special corps or designator for scientific specialists, this group to be supervised and coordinated by ONR, much like CEC officers are controlled by the Bureau of Yards and Docks, and Intelligence Specialists by ONI. Only in this way can officers be properly guided along directed career patterns, and the Naval service as a whole derive the maximum benefit from their peculiar qualifications.

The officer would be a specialist, true, but no more a specialist than we find today. Such an officer would have, we might say, a horizontal specialty rather than a vertical one—that is, a job specialty rather than a bureau specialty. Instead of rotating, say through only BuOrd or only BuShips billets of all types, he would rotate throughout the whole Navy in billets of one type. This officer would be technology oriented rather than organization oriented.

The purpose of the program proposed here is certainly *not* to withdraw a few officers from the rest of the Navy. *Rather, it is to integrate the whole world of scientific research into the main current of the operating Navy.*

The problem of specialization, *per se*, is one peculiar to the Navy's officer corps organization and its traditional concepts. We have long cherished the idea of the unrestricted line officer capable of succeeding to command at sea and managing the shore establishment during his periodic tours ashore. This concept is on shaky footing today. We see the need for increased specialization throughout the Navy. Not long ago, the supply officer of a destroyer was a line officer; now, he is a member of the Supply Corps—his duties are that much more specific. The Commander of a Naval Shipyard is no longer a line officer but also a specialist. Ordinary vessels have a line officer for Chief Engineer, but some of the big new carriers have engineering specialists, and the



Official U. S. Navy Photograph

Gas diffusion experimental apparatus. Navy Scientist recording data.

Official U. S. Navy Photograph

A Navy scientist studies a metal surface at 20,000 magnification through the use of an electron microscope.

Nautilus and *Seawolf* require, not only specialists with submarine dolphins, but with extensive nuclear engineering training as well. Command at sea might well be referred to as a specialty unto itself. The effective current day line officer, a graduate, perhaps, of a general line school and war college course, should be a management specialist with a good deal of training in strategy, logistics, and the psychology of leadership. The age of specialization is upon us, and its effects will become increasingly apparent in the Navy of the future.

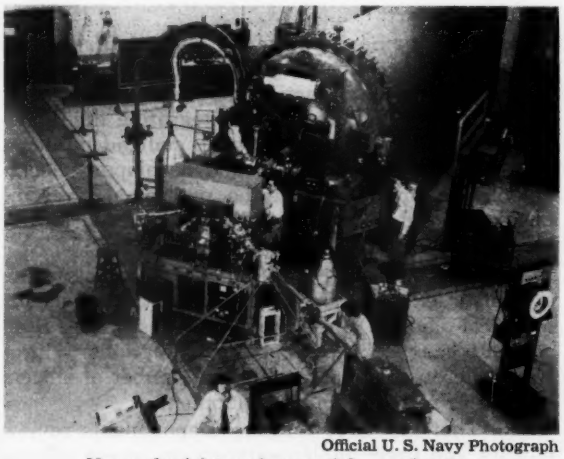
Do these arguments necessarily carry over into the subject at hand, the need for scientific specialists in the officer Corps? Why not depend upon civilian personnel to be the actual scientists? To answer this, it is only necessary to point up to the need for a much larger force of civilian scientists in the Department of the Navy, and to show how their work will be concomitant with Naval Officers but with neither supplanting the other. The need for the officer is in mangement and liaison positions. One must realize that all research, including basic research, is in fact directed. For example, the Navy and ONR in particular, spends tens of thousands of dollars annually on basic research in the fields of radiation and oceanography; very little in cryogenics and spectroscopy. The reason is probably obvious; the former are considered at the present time more likely to produce results which might have naval applications; the latter less likely. Of course, this direction is a calculated risk. A naval officer, with his broader background, but with scientific training also, can be of most help in making such decisions. In applied research, the importance of this direction and the liaison between engineer and scientist is more easily recognized.

It might then be argued that the Navy's scientific program has been staffed with engineering officers in the past, that their administration has been most effective, and that this policy should continue. It is necessary to point out that some of these officers were really scientists in substance, and that, if they weren't, in most instances they were active only in the strictly applied science and development end of the R&D program. As pointed out before, it will become increasingly necessary for the Navy to be active in the most fundamental aspects of science in the "new look" climate. There are those, of course, whose experience transcends customary boundaries and have knowledge in several fields, but they become rarer as the need for scientific specialization increases. It certainly does not follow that a competent engineer is necessarily a capable scientist, or vice versa. I would hate to see some mathematicians I have known try to drydock a ship; whereas, the guts of an analogue computer might be so much spaghetti to a very capable ship's superintendent.

Here I have touched upon a point, which is perhaps the crux of the argument. In discussions, engineers, especially, fail to see that there does exist a vital and necessary difference between the scientific and engineering approach or attitude toward all problems. Any scientist, irrespective of his specialty, will be excited about the recent revelations concerning the breakdown of the physical law of parity; the engineer has probably not even considered it. Only a physicist could appreciate the difficulties in design and benefits to be gained from a new particle accelerator. When the Navy buys such developments, it should have officers qualified to understand the reasons behind the dollars. Contrariwise, there are many tasks expected of a Navy engineer for which a sci-

Official U. S. Navy Photograph

Navy scientist examines cavity of a particle accelerator at the Naval Research Laboratory.



Official U. S. Navy Photograph

Navy physicists using particle accelerator.

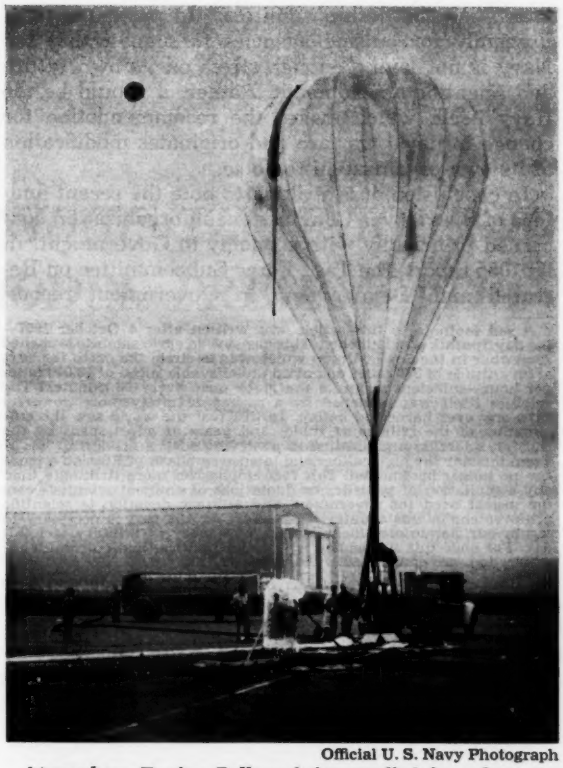
entist is patently unqualified by virtue of his training.

There should be a corps of scientists in the Navy, who first have basic knowledge of the Navy, preferably by the time-honored method of going to sea for several years, and who, secondly, are qualified scientists by virtue of their subsequent graduate training. But the process cannot stop with the completion of formal education. A scientist must be nurtured in his own field. He must maintain his competence through constant use of his knowledge, by continued study, by association with other scientists and with professional societies, and by application of his knowledge to actual research problems. No one would consider giving a trained physician two years of medical experience and then rotating him to another field. The Navy does not do this with its Medical Officers; why so then with a nuclear physicist or an organic chemist, with as much education? We have special categories for dentists, lawyers, hydrographers, photographers, civil engineers and intelligence officers, but not scientists.

There should be no fear that the scientist would have to create his billets. The billets mentioned above are available already, stretched from Woods Hole, Massachusetts to Point Loma, California, and in many interservice organizations such as the Armed Forces Special Weapons Program (AFSWP) and the newly organized Armed Services Technical Information Agency (ASTIA). An officer's career pattern would be easily established by the controlling agency, ONR.

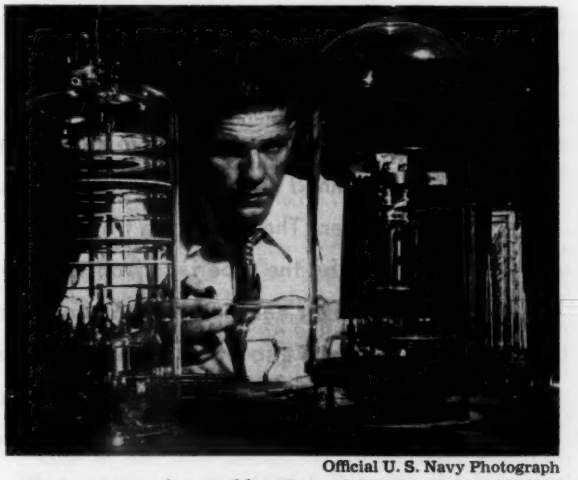
The establishment of a special designator would carry over into the Naval Reserve. This would have a very salutary effect on the Research Reserve. It would greatly aid in mobilization and in the procurement of new personnel. The morale factor, an *esprit-de-corps,* that belonging to a special group can foster, is especially valuable in keeping alive an organized reserve which these scientists compose.

Lastly, there are several semi-political considerations which cannot be neglected. The Navy is in



Official U. S. Navy Photograph

Atmosphere Testing Balloon being readied for release by members of the Naval Research Laboratory.



Official U. S. Navy Photograph

At one stage of assembly, Howard L. Vess takes a brief look at 2 unusual types of tubes which have been constructed for research work.

competition with the Army and, especially, the Air Force for the public favor. We are forever under the scrutiny of Congress and of John Citizen. Convinced as we are of the need for the future of naval warfare, it is necessary to convince Congress and the public of this. Sentiments in the public press are often manifested by such phrases as "the hidebound

brass," or "battleship admirals." In particular, it is unseemly for outside agencies to suggest that the Navy is not laying enough stress on its own future and scientific development. Rather, it should be the Navy itself, which makes the recommendation for change in naval warfare and originates modification of its own organization to do so.

In conclusion, it is striking to note the recent findings of the Hoover Commission, an organization concerned principally with economy in Government. In its 1955 report, the Task Force Subcommittee on Research and Development in Government recommended, in part:

"11. That the Secretary of the Navy and responsible senior Navy officers give strong administrative support to the new functions of the Office of Naval Research in coordinating and integrating the development program of the Navy. A staff adequate in size and of highest research and development competence be provided, and the programatic recommendations of the Office of Naval Research be implemented.

"12. That each of the Military Departments make a realistic examination of their growing needs for technical officers. If need be, as the Task Force Subcommittee expects, expand their programs to provide generously for an expanding number of officers trained in research and development.

"13. That the three Military Departments review policies and their implementation on career officers in research and development. Move toward limiting the areas of rotation of research and development officers in technical assignments, and increase the time period of assignment in a position."

A sad footnote to this article was written after 4 October 1957—the day *Sputnik* was launched. This day saw an earth satellite launched somewher in the Soviet Union which was to circle the earth for days at an altitude of 560 miles and at an unbelievable speed of 18,000 miles per hour—sufficient to girdle the globe once every 96 minutes! The satellite itself was launched by a rocket definitely more powerful than any ever harnessed before. In this feat the world saw the culmination of the billions of rubles and years of effort spent by the Russian scientific organization in achieving such a masterful "first." From this day the high caliber and intense emphasis of Russian science can no longer be doubted. This fact emphasizes more strikingly than any compilation of statistics or quotations of eminent scientists can, the urgent need for government and military devotion to scientific achievement in this country. This effort on our part is necessary to regain our heretofore unchallenged supremacy in military technology. For once this supremacy is lost, our political and cultural leadership, too, are challenged.

As a part of a program for improving and simplifying flight instruments, the Naval Research Laboratory has developed a new type television screen. The screen, perfectly transparent, is made by a process of depositing the phosphor on the tube in an extremely thin film. A much sharper picture is obtained than possible with the conventional grainy textured powdered screen. The use of the transparent film eliminates most of the light reflection by the tube face from outside sources, thus making it possible to produce a clear picture with good contrast even in bright daylight. The development also offers significant possibilities in color television, since transparent films, deposited in layers, can be made to respond in different colors by proper control of electron impingement.

JOHN LA DAGE

A UNIQUE TECHNIQUE IN MARINE MODEL PRESENTATION

THE AUTHOR

is Associate Professor of Naval Architecture at the United States Merchant Marine Academy. He was graduated from the New York State Maritime College in 1938 and from Princeton University in 1948. From 1934 to 1943 he served intermittently in various capacities from Ordinary Seaman to Second Officer in U.S. merchant vessels. One of his voyages took him, during World War II, to Murmansk where his ship was sunk by German action. He joined the faculty of the Merchant Marine Academy in 1943 where he has remained to date except for a brief interval at Princeton to complete his education. He is a member of the New York Metropolitan Section of the Society of Naval Architects and Marine Engineers, the author of several books on technical marine subjects as well as of numerous articles in various marine periodicals.

Lovers of ships and the sea and students of maritime history now have another "Mecca" toward which to direct their devotion. For now nearing completion at Bethlehem, Pennsylvania is a model display of startling originality as well as considerable breadth of historical perspective.

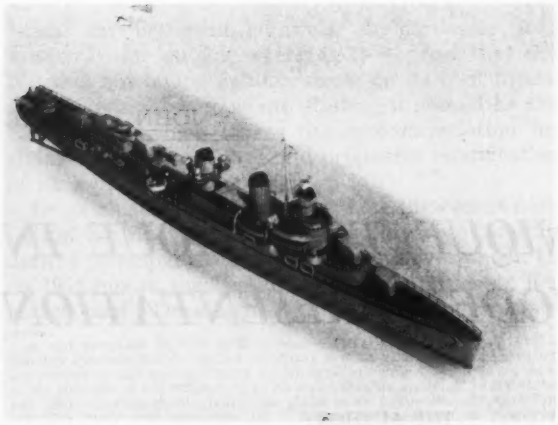
Visitors to the General Office Building of the Bethlehem Steel Company will find the corridors of the first floor filled with marine murals, prints and photographs of great technical and historical interest. The nautical enthusiast, however, will linger longest in the Model Room where some one hundred ship models gleam in a colorful Lucite sea. The models, all built to a scale of 1/32nd of an inch to the foot, depict the development of each major type of naval and merchant ship from the *Bangor*, a passenger and cargo vessel built in 1844 to the latest type merchant and naval vessels. Although the models represent vessels built only by the Shipbuilding Division of the Bethlehem Steel Company (or its direct predecessors), the scope of the model building project is broad enough to cover almost every principal type of craft built during this period.

The story of this program of model construction and display is a fascinating one, extending over a period of several years, and marked by a series of ingenious solutions to the scores of problems which arose in developing what amounts to a completely new technique in marine model presentation. Drawn into the vast project were the talents and facilities of the master craftsmen in the Model Shop and other areas at Bethlehem's Quincy, Massachusetts shipyard, the ability of the plastics industry which had to cast what are probably the largest blocks of Lucite ever produced, the skill of several prominent engineers and design consultants and the combined maritime historical knowledge of people from such diverse places as the Peabody, Mystic and Mariners Museums, the National Archives, the Massachusetts Institute of Technology, and of course, the far-flung units of the Bethlehem organization.

The Model Room is now open to the general public daily and it is to be hoped that those of our readers who truly love ships will have the opportunity to see this remarkable display. Meanwhile a photographic tour supplemented by descriptive text may whet their appetites to some extent.

DESCRIPTION OF THE MODEL ROOM

One of the first things to attract your attention when you enter the Model Room is the beautiful and realistic ship's deck and railings. Their realism is no accident since they were patterned after the decks and railings of the *Independence* and were fabricated and installed by the same shipwrights at the Quincy yard who constructed this beautiful passenger liner. The lustre and beauty of these teak fittings lend an authentic nautical air to the Model Room and put one in the proper psychological mood for inspecting the amazing perfection of the models which surround him.



Bethlehem Steel Corporation
Figure 1. Typical destroyer model.

The models are displayed in showcases arranged in two semi-circles with the merchant ships on one side and the naval vessels on the other side of the Room. The "sea" on which the models "float" consists of thirty huge Lucite blocks, each weighing some 400 pounds. One of the most interesting facets to this story is the employment of Lucite embedments as a means of displaying models and the problems which arose as a result. Lucite embedments, of course, are hardly a unique method of display, but the application of the technique to models and the fabrication of such large blocks is definitely unique.

The fleet of models appears to float, but in addition, the translucent qualities of Lucite make it possible to view the underwater form of the hulls! To the initiated, hull form tells just as vital a story in the development of ship design as does the superstructure. One of the problems related to Lucite embedment arose in connection with this desirability of viewing the underwater form of the models for there is considerable refraction of light passing through Lucite. The Quincy model makers found that they had to construct deliberately distorted hulls in order to make the appearance of the hulls normal as viewed in the Lucite. This problem was particularly vexing when it came to the fabrication of propellers, rudders, shafts and struts. How this problem was solved will be told later.

Our attention is next directed to the strikingly beautiful effects created by the numerous sources of lighting. In the overhead and extending around the cove of the showcases are a series of curved cold cathode lamps which indirectly illuminate the backdrop of blue sky, clouds, "sea" surface and the ship models themselves. These cove lights are supplemented by ceiling spot lights (projectolites) which bring out fuller color tones of the model's hulls. Light is directed through the Lucite blocks both from the side and from "underwater." One series of curved cold cathode lamps attached to the carriages on which the models are mounted directs its light up through ¼ inch sheets of blue-tinted Lucite and provides a colorful sealike appearance to the Lucite blocks on which the models float. All lights except the ceiling spots have dimmer controls which enable the degree of illumination to be varied widely.

THE MODELS AND THE HISTORICAL STORY THEY TELL

As we inspect the models we find that they are arranged in groups showing the chronological development of various types of merchant and naval vessels. The merchant ship side of the display includes models depicting the development of cargo, passenger, tank, coastwise, harbor and special purpose vessels. Similarly, on the naval vessel side are groupings for heavy and light cruisers, destroyers, battleships, aircraft carriers, auxiliary vessels and special purpose vessels. All models being built to the same scale, it is possible at a glance to compare the size and shape of the older with the newer ships. The difference, of course, is marked. One may note, for example, that the *William Crane*, the first of the cargo type, was built in 1871 and is 231 feet in length with a displacement of 1,418 tons. The *Old Colony Mariner*, the most modern of the freighters, is 564 feet in length with a displacement of 21,089 tons.

There may be other model displays in the world which represent such a large number of ships all built to the same scale and covering such a relatively long period of time, but such a display is not known to this writer.

To assist the viewer in studying the development of the various types of vessels, pertinent historical information as well as principal dimensions and characteristics of the ships are imprinted clearly on a leather strip extending along the outside of the showcases. A few sample illustrations will help to grasp the scope of the display. Starting with the cargo ships section, we note that the *William Crane*

Bethlehem Steel Corporation
Figure 2. Models in the display are grouped according to type of vessel. Here are some of the ships in the Heavy Cruiser and Light Cruiser sections.

Bethlehem Steel Corporation

Figure 3. Quincy model maker works on model of the *World Glory*. This is the "topside" part of the model. In the display, this part rests on a platform covering the cavity made by the "embedment" hull.

mentioned above, is one of the early steamers which mark the period of transition from sail to steam. Her reciprocating engine developed power producing a speed of 8 knots. The *Thomas W. Lawson* built in Quincy in 1902 was a sailing ship, the only seven masted schooner ever built. Very few large sailing vessels were built after this time. Included in the cargo group is that very famous ship, the *Patrick Henry*, the first Liberty ship built in World War II.

Moving on to the tank vessel section, we observe a very early type of tanker in the *George Loomis* built in San Francisco in 1895. Her displacement was only 1,457 tons. The difference between this early tanker and the *World Glory* which was built at Quincy in 1954 is startling. The latter has a displacement of 58,265 tons!

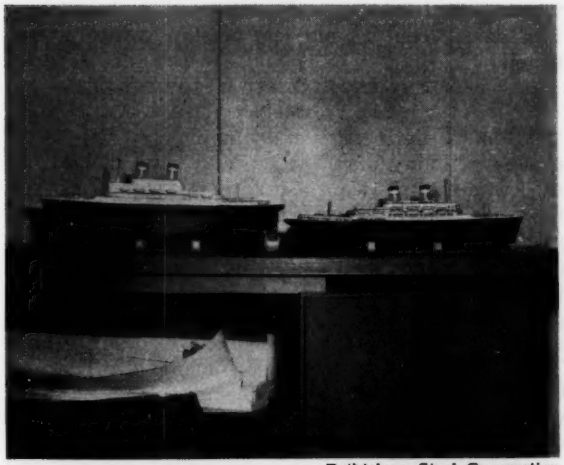
The passenger ship section includes early steamers like the *Bangor* and extends through to the American Export liner, the *Independence*, built at Quincy in 1950. Once again, the increase in size is impressive, the *Bangor* having a displacement of 231 tons, the *Independence* 30,000 tons.

The special purpose group includes such diverse types as drill barges, ore carriers, colliers, refrigerated ships, light vessels, dredges and a Coast Guard cutter. In the harbor vessel group may be noted ferries, tugs and a carfloat. In the coastwise group are trawlers and passenger types.

Turning now to the naval side of the model display, we start with a study of the development of heavy cruisers and go all the way back to 1863 when the *Franklin*, a steam frigate and the forerunner of the heavy cruiser was rebuilt from the 1815 sail frigate of the same name. This vessel was the flagship of Admiral Farragut. Other famous ships in this group include the *Olympia*, the flagship of Admiral Dewey in the battle of Manila Bay; the *Northhampton*, built in 1929 and sunk in the Battle of Tassafaronga, Solomon Islands in December, 1942; and its namesake built in 1951 as a Tactical Command Ship, the first such type ever built.

In the light cruiser grouping our eye is attracted by the *Birmingham* built in 1907 and distinguished by the fact that she was the first naval vessel from which an airplane was launched.

The oldest ship in the destroyer section is the *Adams* which was technically a sloop-of-war or Corvette. Constructed of wood in 1874, this ship was a forerunner of the modern destroyer. Another destroyer prototype is the *Farragut* designated as a Torpedo Boat. This ship was built during the Spanish-American War period and also saw service in World War I. Also noted in the destroyer section are such vessels as a Torpedo Boat Destroyer; an old "four-piper" destroyer built at the end of World War I; the *Gridley*, the first single stack destroyer built in this country; and the *Willis A. Lee*, the first Destroyer Leader constructed in the post-World War II period. During the time period covered by the display, destroyer lengths increased from 185 to 493 feet.



Bethlehem Steel Corporation

Figure 4. On the right is a scale model of the *Independence*. On the left is a mock-up of the way the model would look if the topside part were placed on an "embedment" hull.

In the aircraft carrier section, there are two ships both with the same name—*Lexington*. The older ship (1925) was the first USN aircraft carrier built as such. She was sunk in the Battle of the Coral Sea in 1942. The newer ship (1942) also saw extensive World War II service. Since Bethlehem shipyards have not built any of the Forrestal class carriers, the exhibit is not quite up to date in this respect, one of the few instances where this is true. One is impressed however that the shipbuilding operations of one company can cover so completely the important

types of ships built in this country for more than one hundred years.

One of the most interesting groupings contains models of naval auxiliary vessels including such types as a net layer, an ocean tug, an ammunition ship, landing craft, troop transports and even the so-called Texas Tower or off-shore radar warning station. (The latter station is operated by the U. S. Air Force).

Also very interesting are the special purpose vessels such as submarines, a destroyer escort and a fleet oiler. Another regrettable absence from the display is the atomic-powered class of submarine.

The development of battleships takes us all the way back to the monitor *Patapsco* built in 1862. This single turreted iron-clad vessel was used against the Confederate forts in 1863. The most modern battleship shown is the *Massachusetts*, the "Mighty Mamie" of World War II.

All in all, the model display should fascinate layman and student of maritime history alike, both for the technical realism and beauty of the models as well as the century old tale of ships which it has to tell.

PROBLEMS ENCOUNTERED IN THE USE OF LUCITE EMBEDMENTS

Although the construction of over one hundred models of many different types of ship all built to the same scale is a project of monumental proportions, we shall not dwell on this element of the program since the unique aspect of the Model Display concerns the use of Lucite embedments. The problems surrounding this novel technique of model presentation were so pervading that, in discussing a possible title for the article, one wag suggested: "I Love Lucite"! From the comments overhead at Quincy, however, this writer feels that all concerned with the project and the headaches which developed, wished they had never heard of Lucite. The final results, however, more than justified the faith and hopes of the project's designers.

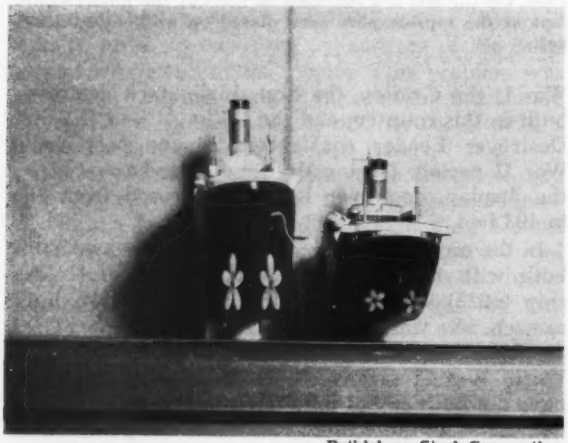


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Figure 5. These are the same models seen in Fig. 4. Note particularly the necessary distortion of the propellers on the "embedment" hull.

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Figure 6. The allowance required to be made for shrinkage in the casting process is clearly visible in this view of the topside model of the *Venore* resting on its unpainted "embedment" hull.

Refraction Problems:

It was discovered early in the project that the "underwater" portions of the model's hulls would be considerably distorted by the refraction of light passing through the Lucite. Length and breadth of the hulls could be built to scale, but the vertical underwater dimensions had to be increased 2½ times. This was found empirically by drilling 1 inch holes in a sample Lucite piece and using a camera range finder to find the apparent height of the holes. So in constructing the embedment hulls for use in casting the Lucite blocks, the distance between waterplanes was increased 2½ times the actual scale distance. This led to some interesting problems in routing the hulls.

The interest developed in refraction started the Quincy model makers on a study of this subject and it was found that trichlorethlyene has the same index of refraction as Lucite. This fact was of great value when it came to fabrication of model propellers, for example, since the appearance that distorted propellers would have when embedded in Lucite was easily determined by immersing them in trichlorethlyene. All vertical dimensions on the propellers, propeller hubs, shafts and struts also had to be increased 2½ times. Some complex fabrication problems ensued with shafts, for example, being machined on an eccentric hub to achieve the distorted shape. The accompanying photograph will show better than words how the normal helicoidal shape of a propeller blade had to be distorted to produce the normal appearance when embedded.

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Figure 7. In this view, "embedment" hulls are resting in a mold box prior to pouring the liquid Lucite.

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Figure 8. Liquid Lucite is poured in the mold box.

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Figure 9. The mold box is brought out of the oven.

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Figure 10. The rough cast block must be put into an insulated box immediately to prevent too rapid a cooling rate and consequent induction of internal stresses.

Preparing the Embedment Hulls:

One point which should be made clear concerning the Model Display is that there actually are no underwater hulls on the models as one looks at them. There are only cavities cleverly painted. The models, from the waterline up, are mounted on platforms installed flush with the top of the cavity. The cavities resulted from the casting process where properly distorted hulls were utilized. These hulls are identified here as "embedment" hulls. The appendages (propellers, rudder, struts and shafts) however are actually there.

In constructing the embedment hulls, a great many vexing problems were encountered. It was found first that in the casting process, a considerable shrinking occurs in Lucite from the liquid to the solid state. This necessitated constructing the distorted embedment hulls with a shrink allowance. After experimentation (and many headaches), empirical data were developed which enabled properly formed hulls to be constructed.

Before the wooden blocks from which the embedment hulls were fabricated could be routed, they

had to be baked for 1 to 2 hours at 250° to remove moisture from the wood and shrink it to minimum size. The finished hull was first sanded, then similarly baked before applying some ten coats of enamel. The hull was then baked again, recoated and rebaked as many times as was required to obtain a quality finish!

The appendages were then cemented to the embedment hull and coated with a special fluid (Butyl #2) which assures the best possible adhesion of cast Lucite. The hull was then ready for the casting process.

The hulls are placed in the mold box, positioned of course as they are to appear in the Display. All models in the Display, by the way, are positioned so that their centerlines are angled 30° off radial lines drawn between the two arcs which form the ends of the Lucite blocks. The hulls are cemented to thin (¼ inch) Lucite sheets which help to obtain a flat plane for the uppermost waterline of the hulls.

Liquid Lucite is now poured in the mold box and the box placed in the curing oven.

Removing the Embedment Hulls from the Rough Cast Lucite Blocks

Among the peculiar properties of Lucite is the large shrinkage in volume which occurs in the transition from liquid to solid. In addition to the problem of providing for shrinkage in the size of the embedment hull, this led to another problem—the creation of high stresses within the Lucite and any material embedded therein. Lucite also has a high coefficient of expansion and is a poor conductor of heat. These properties created additional difficulties when it came to removing the rough cast blocks from the curing oven, removing the embedment hulls and transporting the blocks to the Model Shop. First, it was found necessary to place each block in an insulated box immediately upon removal from the curing oven since any abrupt change in surface temperatures around the block would accentuate the internal stresses. Also, after some trying experiences with the internal stresses set up around the embedment hull as the block came out of the oven, the need for immediate relief became evident. This was accomplished by promptly removing a transverse section of the hull amidships using a drill and chisel. It was then possible to remove the remainder of the hull in a more leisurely fashion. This was accomplished by driving both ends of the hull toward the center where the material was removed initially and then "jacking" the ends out vertically. It should be observed that these operations are carried out while the block is in the insulated box. The need for extreme caution is further illustrated by noting that a layer of insulation (Homasote) had to be placed over the top of the block and "windows" cut through the layer in order to complete the operation of removing the embedment hulls.

This brief description of the problems encountered in casting the blocks and removing the hulls can only suggest the difficulties which had to be surmounted. Consider for example, the presence of bulbous bows or ram bows which required very careful work to prevent cracks or "crazes" from forming as the hulls were removed. Trouble was experienced especially with the top edges of the cavity, these edges apparently being high in internal stresses. The cooling of the block, even though the rate is slow within the insulated box, causes an increase in the stresses along the sharp edges. The strength of the material may be exceeded and small fractures result.

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Figure 11. Imbedment hulls must be removed immediately from the rough cast blocks. Note the layer of insulation on the top of the block.

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Figure 12. At the Quincy shipyard Model Shop, a master template helps to determine the size of the finished Lucite blocks.

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Figure 13. First operation in finishing the Lucite blocks is to cut them to rough size with a bandsaw.

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Figure 14. A "dry" machining process of all surfaces is the next step. The hose is used to direct an air jet at the cut helping to keep down the temperature around the cut.

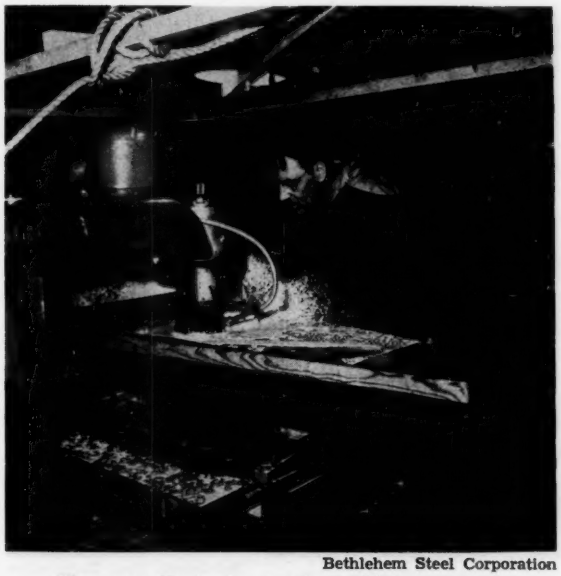

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Figure 15. Next, the "wet" machining process.

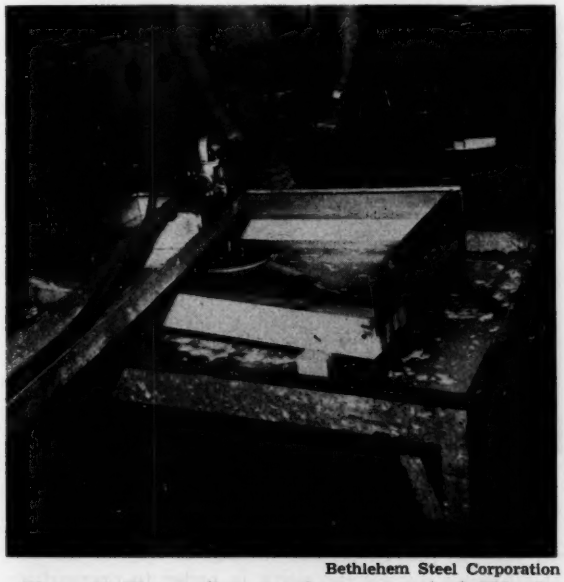

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Figure 16. Five sanding operations are required. This also is a "wet" process.

FINISHING THE LUCITE BLOCKS

Finishing the rough cast Lucite blocks in preparation for shipping them to the Model Room at Bethlehem involved several intricate operations and required many innovations since the model makers had never worked with a Lucite medium before. Included among the operations were cutting to rough size with a bandsaw; dry machining and wet machining on the milling machine; a series of sandings; and final buffing and polishing.

The rough cast blocks were some 4½ inches thick. The finished blocks had to be brought down to 3½ inches. The first operation, bandsawing, reduced the outside surfaces of the block to within ⅜ths of an inch of the finished size line. The next operation of the milling machine brought all surfaces down to within .040 inch of the finished size. As shown by the photograph this dry machining process is quite spectacular with the snow-like Lucite flaking storming down from the machine in all directions. (An

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Figure 17. This huge buffing wheel puts the final polish on the Lucite blocks.

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Figure 18. The finished Lucite blocks are lifted carefully into place in the Model Room at Bethlehem.

air jet was played on the surface in way of the cut at all times during the work in order to prevent an undesirable rise in the temperature around the work.) The ends of the blocks offered special problems since they had to be finished to arcs of a circle, the radius of the inside arc being 5 feet 3½ inches; the radius of the outside arc, 7 feet 9 7/16 inches.

The final machining operation for the upper and lower surfaces of the blocks is a wet machining process using one part of Solvac Soluble Oil to twenty parts of water. The liquid mixture serves as a more effective coolant than the air jet in this most important and ticklish operation. After wet machining the thickness of the blocks is 3.520 inches, the remaining .020 inch being left for removal by sanding.

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Figure 19. The platforms rest on legs which extend down into the cavities made by the embedment hulls during the casting process. The topside models fit on top of the platforms and are held in place by dowels.

It may be noted that the sides of the blocks are actually cut back to 1/64th of an inch past the exact size to make the blocks fit snugly in the Display in order to allow for expansion due to temperature differentials in the Model Room.

The sanding operation consists of using a series of progressively finer papers with each paper removing the scratches of the previous sanding. Five grades of paper were used. A special problem was encountered on the top surface of the blocks since the cavities are exposed and their edges have to be protected against deformation. With this thought in mind, Lucite platforms constructed of ¼ inch sheets, were made to fit the contour of the top of the cavity. Legs extending down into the cavity support the platform. The legs naturally have to be carefully cemented at their bases. Thus while the sanding operations as well as the later polishing steps are proceeding, the platforms protect the edges of the cavities from being damaged. These platforms are later used in the exhibit to support the topside models.

After the sanding has been completed and before polishing begins, the blocks are carefully cleaned and the cavities painted. The insides of the cavities are carefully sanded before painting. The amazing attention to detail which characterizes the entire model project is nowhere better illustrated than by the manner in which this painting was accomplished. Although it is readily possible to determine the true

color of the ship's bottom paint, this true color is useless as a paint for the inside of the cavities since every source of illumination and its color in the exhibit affects the apparent color of the cavity paint. To solve this problem, a mock-up was built simulating the exhibit conditions of lighting both in intensity and color. A sample block of Lucite was set up in the mock-up and paint mixes applied to it until the exact shade desired was developed. In each case of color match several people were consulted until all were satisfied that a true match had been achieved!

The type of paint used had to be carefully selected since some paints will craze the surface of Lucite. The paint was applied by spray gun.

The block is now ready for polishing. The accompanying photograph shows the large (30 inch diameter) buffing wheel which the Model Shop had to construct for this purpose. Buffing was accomplished with the wheel revolving at 415 RPM. A light coating of parafin wax is first applied to the face of the wheel, then a light dressing of buffing compound. This operation removes all sanding scratches and produces a highly polished and gleaming surface.

One more operation remains before the block is shipped to Bethlehem. The Lucite platforms have to be painted so that they appear to have the same color as that at the top of the cavity. This will not be exactly the same shade of color as that which applied to the inside of the cavity since the latter is subjected to different sources of illumination than the platform.

This completes the finishing operations on the Lucite blocks and one can only marvel at the tremendous scope of these operations, especially when it is considered that the exhibit contains thirty blocks!

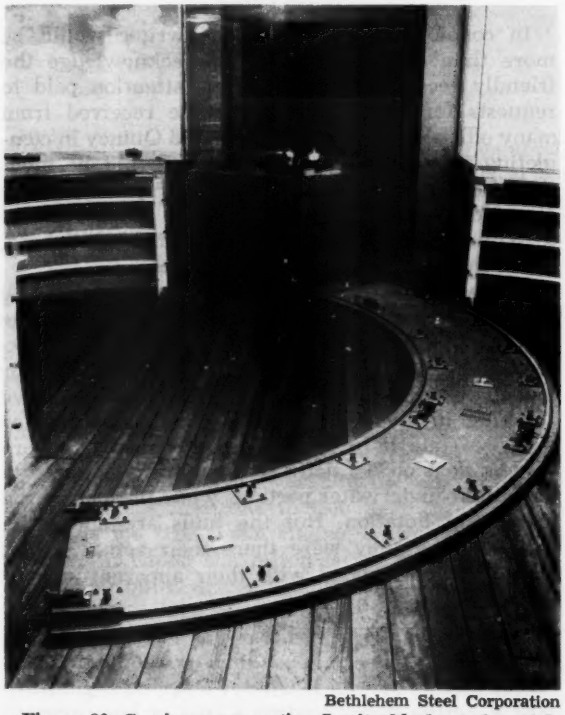

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Figure 20. Carriages supporting Lucite blocks and models can be rolled out of the showcases for routine cleaning and maintenance.

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Figure 21. Carriages are now in the rolled-out position.

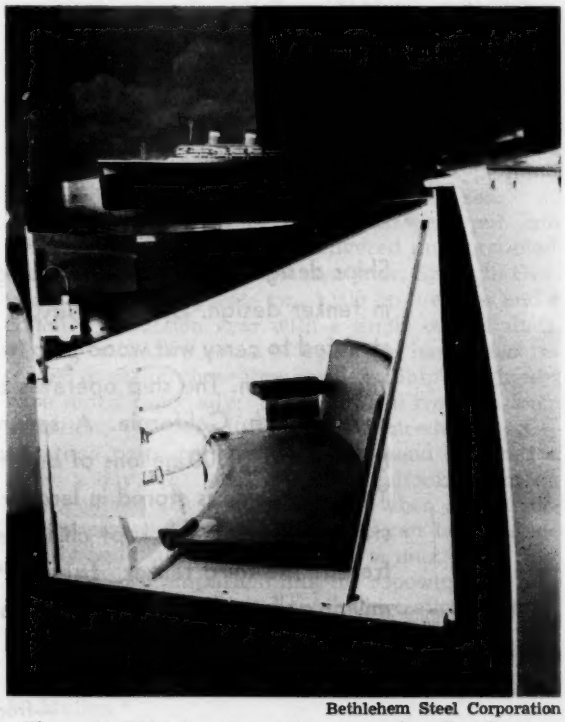

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Figure 22. This view shows the end section of a showcase with a ship model, the Lucite block which supports it, the carriage, "underwater" lighting, and a dolly which is used by the electrician for repairing electrical fixtures. Also visible is diagonally slanted sheet of Lucite which gives the blue undersea effects.

CONSTRUCTING THE MODEL ROOM AND ITS FITTINGS

The ingenuity displayed in constructing the models and the Lucite blocks in which they are displayed was duplicated by the accouterments which surround them in the Model Room, not only enabling them to be displayed to best advantage, but permitting them to be installed and maintained efficiently. For those readers who are interested in the technical problems which arose and how they were solved, a brief description of this phase of the project is supplied.

The first step was to build a mock-up of the Model Room which duplicated to full size, one-quarter of the Room. This expedited the design of the cases in which the models are displayed, the carriages on which the models are supported, the tracks and track supports for the carriages, the electrical engineering and the painting of the sky background.

It should be noted from the photographs that the carriages on which the Lucite blocks are supported are mobile; that is, they can be moved in and out of the display cases by rolling them over tracks which are fitted to portable track supports. Since the display cases are semi-circular this raised some nice problems with regard to the design of the carriages, leveling and connecting the sections of portable track supports, and arranging the floor plan of the Model Room so that the carriages in their rolled-out position would clear all obstacles. It was vital, of course, that the tracks be level within a very close tolerance. As a matter of fact, the tracks inside the display cases are leveled to a tolerance of within .003 inch! Circular spirit levels on the portable track sections enable this level to be checked before rolling out the carriages.

To maintain the lighting fixtures inside the display cases, a dolly was constructed that rides on a track inside the carriages. The electrician can thus be supported by the dolly as he makes electrical repairs inside the cases or a relamping becomes necessary. The accompanying photographs will serve best perhaps in further illustrating the construction details referred to here.

CONCLUSION

In concluding this article the writer would be more than remiss if he did not acknowledge the friendly reception and courteous attention paid to requests for information which he received from many officials both at Bethlehem and Quincy in completing the necessary research. It should be mentioned also that architects for the project were the New York firm of design consultants: McKim, Mead & White. Plastics Development, Inc. of Attleboro, Massachusetts, cast the Lucite blocks.

The writer is gratified that he was permitted to observe this unusual project as it developed. The technique involved may well lead to further exploitation of the use of Lucite embedments for model display purposes. Certainly the imaginative thinking involved in the project is amazing. For here, to state it briefly, is a model display where models float on a Lucite sea making it possible to view their underwater portions while preserving the illusion of flotation. But the hulls are not really there—and if they were there their actual shapes would not correspond with their apparent shapes!

Ships designed for specialized cargoes include three interesting variations in tanker design. ***Duncan Bay***, a 20,000 DWT tanker, is especially constructed to carry wet wood pulp, which is loaded and unloaded by a pumping operation. The ship operates between Duncan Bay, British Columbia, and Antioch, California. A second tanker, ***Tropicana***, is designed to transport 650,000 gallons of bulk fresh orange juice from Florida to New York. The juice is stored in large vacuum sealed tanks of chromium-nickel stainless steel and is kept chilled at a temperature of 28° - 30° F during transit. The third tanker, ***Angelo Petri***, is designed to transport over two million gallons of bulk wine in 26 stainless steel tanks. The ship will also carry lubricating oil, alcohol and edible oils. It will operate between Stockton, Port Newark and Houston.

—from "Marine Engineering/Log," September 1957

FRENCH EXPERIENCE WITH FREE-PISTON ENGINES

ACKNOWLEDGEMENT

This is an abridged version of an article published in the May 1957 edition of "Mechanical Engineering." *The authors are M. E. Barthalon and H. Horgen.*

As of June 1, 1956, ninety-five standard GS-34 SIGMA gasifiers had been delivered and put into operation throughout the world, under practically every condition of climate and operating load, with widely different supervision crews—merchant-ship engineers, natives, navy temporary crews, railway mechanics, steam-power operators. The installations cover all fields hitherto covered by diesels, with shaft output running from 1000 to 8600 hp.

This is the free-piston engine, a two-cycle diesel cylinder in which the piston is not connected to a crankshaft but is driven against a cushion of air and bounces back. The piston (actually a power piston and a compressor piston joined together) shuttles between combustion chamber and air cushion, and in shuttling it pumps a volume of air, for its own supercharging and to feed a turbine. Shaft output is that of the turbine.

ELECTRIC GENERATING SETS

A typical arrangement is the power station of an ore-mining concern at Metlaoui in the Tunisian desert. It comprises two 600-kw turbo-alternators, each fed by a GS-34 gasifier, with a third gasifier provided between the first two, since this is a 24-hr per day, 11-months per year operation. The stand-by can feed either of the two turbines within two minutes. The set was started in December, 1953, and has now completed 25,000 hours without a single stop for turbine maintenance.

The turbine was opened after 12,000 hours and was found in perfect condition, ready to run twice as long without another opening. This is proof that continuous full-power operation can be obtained from turbo-alternators fed at low temperature by free-piston gasifiers.

Outstanding features, as compared with a similar diesel installation, are the small cost of stand-by and the use of heavy fuel.

One 6000-kw set, using eight gasifiers, has been in service since December, 1955. Most notable characteristics of the set are: (a) Specific fuel consumption of 0.545 lb. per kwhr at terminals; (b) possibility of running at full load while one gasifier is disconnected, stopped, repaired, and connected again; (c) very small total weight (120 tons); (d) small size of alternator, when compared with a 200-rpm diesel-driven unit; (e) absence of large concrete foundations.

SHIP PROPULSION UNITS

The French Navy has been interested in the development of free-piston machinery since the beginning of 1938. In the spring of 1953 a prototype mine sweeper became the first free-piston ship at sea.

Two cargo vessels of 1,100 tons were put into operation in 1953 and have delivered uninterrupted service along the Atlantic coast from Spain to Germany. They incorporate two 1,000 hp turbines and a common reduction gear with a single output shaft. More than 25,000 hours of operation have been recorded at sea on these four gasifiers. Ship's engineers have noted especially: (a) Complete freedom from vibration; (b) very little attention needed at sea—only one point per gasifier needs hand lubrication twice a day; (c) small number of hours spent on maintenance; (d) good flexibility when maneuvering—every speed ahead or astern can be obtained readily and maintained from zero to maximum.

A 6,000-shp propulsion unit for repowering a Liberty ship under a Maritime Administration contract has been bench-tested and is just undergoing sea trials. The fuel consumption of Bunker C is 0.43 lb per shphr. A complete description can be found in McMullen.*

LOCOMOTIVES

The first locomotive, powered with one GS-34, was put into regular passenger service in 1952, and

*"A Free-Piston Propulsion Plant for a Liberty Ship," by J. J. McMullen. ASME Paper No. 55—OGP-14.

has since completed 150,000 miles. The 1,000-hp turbine has a maximum speed of 12,000 rpm at 78 mph. A direct mechanical transmission is used.

Two 2,200-hp locomotives are being built. When compared to diesel-electrics, the most interesting features are: (a) The use of Bunker C fuel; (b) the simplicity of transmission (direct mechanical), and engine (two cylinders against 12 or 16; no connecting rods, crank shaft, valve drive, and so forth); (c) small maintenance cost, owing to the elimination of many mechanical and electrical parts and to the smooth engine torque; in the original locomotive, after 150,000 miles, the grinding marks on gears were still visible.

COMPRESSOR AND PUMP DRIVES

Only one application to a water-pump drive has been registered so far.

A large compressor plant is under construction for an international chemical company. It is notable for the absence of gears and the very small amount of stand-by (2 gasifiers) when compared to installations using reciprocating machinery. As compared with gas-driven compressors, fuel or gas consumption is much lower.

DEVELOPMENT PROBLEMS

Operation and control

At full load, the travel of the free piston corresponds to:

1. The maximum safe Outside Dead Point (which is ODP max, minus a safety margin).
2. The minimum possible IDP for acceptable diesel-ring life (compression pressure is 1,200 psi at present rating).

Throughout the upper range, speed control for relatively slow load change was easily obtained by controlling the fuel rack directly from the turbine governor.

But it is not possible to shorten ODP below the point where scavenging becomes insufficient, or to increase IDP above the point where ignition temperature is no longer reached (200 psi) by compression. Below this "technical minimum" it became necessary to adapt gas flow to the turbine by means of a bypass.

A satisfactory solution was developed which consists of a two-seat valve controlled from the turbine governor; it works first as a bypass to atmosphere, then as an overspeed throttling valve to the turbine, and therefore solves both the low load and running-off speed control. The valve takes 0.7 sec to travel its full stroke.

In marine propulsion units a similar valve is used, the difference being that the reversing stages take the place of bypass to atmosphere. Here the valve takes three seconds for its full stroke.

Operating stability

This is defined as the ability to keep piston motion within the limits of ODP min and IDP max, and the opposite extreme at which the engine stops. One wrong stroke stops the engine. Since the motion of the bypass valve is so fast, full load to idling must be achieved within one second: In a marine installation with a reversing valve, full load to idling to full load must be achieved in three seconds—without infringing the stability limits.

Detailed study established boundaries for semi-stable operation, while careful measurements of the time lag and delivery capacity of the two servos involved (stabilizer and fuel-injection-timing servos) helped improve their characteristics. It was found possible to maintain IDP's and ODP's within the boundaries defined for semi-stable operation and thus keep the gasifiers running in spite of the fastest load changes.

Part load consumption

The specific-fuel-consumption-vs.-load curve shows that when power is decreased there is a slow increase of fuel consumption due to progressively decreasing peak pressure and increasing scavenging ratio. Where several gasfiers serve one turbine, it is possible to stay within the low specific-fuel-consumption range by stopping one or two gasifiers and using a turbine with two inlets.

Below the technical minimum point, a solution has been developed: Air from the scavenging case is by-passed and recirculated into the compressor suction space. This has been found to push back the stability limits. A minimum idling consumption of 9 per cent of full load value has been achieved.

Independence of gasifiers

In order to be able to disconnect, stop, maintain, and again connect one gasifier while maintaining full-load operation, it was found necessary to fit independent bypass inlet pipes, shutoff valves on cooling, and control circuits. It is possible to connect, within one second, any gasifier on the gas collector as soon as delivery pressure is within 7 psi of the collector pressure.

TEETHING TROUBLES

The number of "teething" troubles met during the first years of field operation of the GS-34 has been limited and is no greater than for a new model diesel. Thanks to the extremely easy accessibility and small size of parts (which were readily available and interchangeable) it has been possible to limit the outage to three days in worst cases.

Ring wear

At an early stage of development, compressor-ring wear was completely erratic, and a special ring had to be developed. Not a single ring of the new design has ever required replacement.

Until recently, the first diesel piston ring was a bothersome problem. The life of this first ring was 500 hours at full load on the original GS-34's delivered in 1951. A slight change in design lengthened this to 1,200 hours, and later changes of design, material, and oils increased the life to an average of 2,000 to 3,000 hours at full load on Bunker C.

Oil consumption

The seals on synchronizing rods were extremely difficult to make oil-tight. Early machines had an abnormally high oil consumption through leakage. Improvements were made on the surface finish of rods, on ring material and design, and on oil flow and drainage. Cooling-oil consumption has now been reduced to 0.025 lb per hr. Gland-ring life has been increased to 5,000 hours.

Fuel-injection system

Piston rings and fuel nozzles and pumps are the only wearing parts left in a free-piston gasifier. Through development, it is now possible to operate the GS-34 with fuel viscosity at the pump inlet up to 6° Engler.

Oil

Oil cooling, an early problem, has been solved by the following improvements: (a) Use of detergent and doped oils. (b) Decrease of engine-case temperatures through improvements in valves and cooling. (c) Elimination of oil leakage from synchronizing rods. (d) Elimination of hot spots in the engine case. (e) Decrease of the amount of lubricating oil (2 lb per hour instead of 4 lb per hour per gasifier).

TRENDS OF DEVELOPMENT

The first stage of practical development of the free-piston industrial engine has been achieved. The GS-34, although new, is a competitive engine. It is time to evaluate the rightful place of the gasifier plant between existing competitors in the diesel, combustion, and gas-and-steam turbine field. Not only efficiency, but also fuel requirements, first cost, maintenance cost, ease of overhaul, installation facilities, weight, space, shaft speed, torque characteristics, lube-oil, and water consumption must enter the calculation.

Efficiency

The computed over-all efficiency of 36 to 37 per cent has been checked on installations of such small outputs as 1,500 kw. The fuel consumption is 10 per cent higher than for the best slow-speed diesels. It is comparable to values for medium-speed diesels and much better than for steam or gas turbines.

Reliability and Maintenance

In a multicylinder installation, the most important reliability factor is the pneumatic power transmission which gives the possibility of individual control and maintenance for each gasifier, the remaining ones taking the load.

Care has been taken to obtain easy maintenance. With the GS-34, stripping and rebuilding are rapid, and the heaviest part to deal with weighs 550 lb. Future emphasis will be on plants using many gasifiers, but the reliability of the individual GS-34 has been steadily increased by better design and reduction of the number of parts, in starting, injection, and synchronizing equipment.

Fuel

The gasifier runs perfectly on the heaviest and cheapest fuel. It is remarkably insensitive to fuel quality, for several reasons. The scavenging of the motor with 400° F air, and the unusually high scavenging-air excess are very favorable for running on heavy sulphurous fuel with reasonable wear. So is the absence of circulating crankcase oil, and this affects gasifier oil consumption. No oil renewal is necessary.

First Cost

This depends on production and standardization. The one standard GS-34 gasfier is used for all powers and all applications, and some standardization of turbines and gears will be introduced. But another way to reduce the first cost is boosting the unit power of the gasifier.

Possibilities are obvious, and will pay off. Increased cooling of compressor cylinder and diesel piston allows higher working pressure. A 7-psi increase will increase power by 12 to 13 per cent. Stiffer pneumatic springs will give better acceleration at the Outer Dead Point, where time is lost. Combined with slightly lighter pistons, a 10 per cent increase in speed and power may be obtained. At least for stationary plants, suction with ram effect already permits a 10 per cent increase in air flow. With other improvements, a reasonable figure for the power increase in the future would be 30 to 40 per cent.

Afterburning to 1,200° F at full load has been incorporated in a power plant now under construction. The temperature rise will give 27 per cent more power, but the turbine is naturally more expensive. Combined with the previous 40 per cent increase, the unit power of the gasifier will be increased by 70 to 80 per cent. The specific lube-oil consumption also will be greatly reduced in this way.

Auxiliaries.

In the future, in both stationary and marine installations, all auxiliaries should be turbine driven from the main gasifiers. Auxiliary power is thus produced on heavy fuel, and maintenance of special auxiliary diesel engines is eliminated. There is economy in weight, bulk, and perhaps in price.

LOOKING AHEAD

The basic policy is to keep the present 1,000-hp (and perhaps 1,500 hp or more in the future) GS-34 gasifier with practically identical design for all the various applications.

For power stations from 20,000 kw up to 100,000 kw, the combination of gasifier and steam cycle is under consideration, heat from the gasifier cycle being used for partial feedwater heating.

The over-all efficiency will be better than for any other cycle. A pure steam plant of 25,000 kw and 28 per cent efficiency may be realized as a combined plant with 34 per cent over-all efficiency. A steam plant with higher power, pressure, and temperature, and 37 per cent efficiency, may be boosted to at least 41 per cent over-all efficiency when combined with a gasifier cycle.

REFERENCES

1. "Les groupes électrogènes à turbines à gaz alimentées par générateurs à pistons libres," by R. Huber, *Schweizerische Bauzeitung*, vol. 72, Oct. 30, 1954, pp. 632–634; and Nov. 6, 1954, pp. 649–652.
2. "Adaptation de la turbine à gaz aux générateurs à pistons libres," by J. Hubert, *Bulletin Technique du Bureau Véritas*, 38e année, no. 1, January, 1956, p. 1.
3. "Production d'énergie et de vapeur par une suralimentation rationelle de chaudières au moyen de générateurs à gaz à pistons libres," by H. Horgen, 4th International Congress on Industrial Heating, groupe VI, section 63, no. 72, (1954).
4. "History of Motorshipping," by A. C. Hardy, Whitehall Technical Press Ltd., London England, (1955).
5. "The Free-Piston Engine Development," by A. L. London and A. K. Oppenheim, Trans. ASME, vol. 74, 1952, pp. 1349–1361.

On display at the Engineering Exhibition in Olympia, England, are several British built versions of the Pescara—licensed G.S. 34 free-piston gasifier, together with a series of gas-turbines designed for use with free-piston gasifiers. The G.S. 34 is capable of developing 1232 gas horsepower, equivalent to about 1000 SHP for marine propulsion. The smallest of the turbine series is a 1000 SHP turbine, with designed inlet conditions of 60 psig and 840° F, for use with a single gasifier. The largest turbine, a 10,000 SHP design, is intended for use with ten of the G.S. 34 free piston gasifiers in parallel. The turbines, described as multi-stage axial type with reaction free-vortex blading, were built by the Brush Electrical Engineering Company, Ltd.

* * * *

Experimental production of ultra-high strength steel by the National Bureau of Standards has resulted in a 0.4 per cent carbon alloy steel having a yield point of 235,000 psi and an ultimate tensile strength of 285,000 psi. At the same time, ductility and impact strength have been kept to sufficient values for structural application. Martensitic structure was obtained by a conventional oil quench from 1650° F, followed by a double tempering in a range of 400° F to 500° F.

—from "Mechanical Engineering," August 1957

DR. ROBERT BILINSKI

A LOOK AT ONE ELECTRONICS PROBLEM—ELECTRONIC TEST EQUIPMENT

THE AUTHOR

A combat veteran of World War II and recipient of the Bronze Star Medal, the author completed three years of army service during which time he rose from the rank of private to the commissioned ranks. Upon completion of his military service he entered Albright College where he carried a double major—Business Administration and Psychology. After receiving his B.S. he decided to further pursue his studies in Psychology and did graduate work at Columbia University, the University of Missouri, and Oklahoma A & M and received three Masters Degrees and a Doctorate. Since completion of his graduate studies where he was particularly interested in Research and Industrial Psychology he accepted a research position with the Navy Department. He has been doing research at the U. S. Navy Electronics Laboratory at San Diego, California since 1952 as a research psychologist with particular emphasis upon man-machine relationships, human engineering with respect to electronics equipment, and maintenance of electronics equipment.

THE AVERAGE destroyer today has more than 3,200 electron tubes and for each tube has about seven condensors and seven resistors, all with individual life spans. Thereby, there are about 50,000 potential breakdown possibilities, each having its own life span, which the shipboard electronics technician must be prepared to locate.

An electronics technician aboard ship today is responsible for putting new equipment into operation, maintaining equipment so that it continues to operate, and repairing equipment that has broken down. Many test equipments are available for helping him to do these jobs efficiently. To place into operation and to maintain electronic equipment, the ET is aided by test equipments such as signal generators, voltmeters, ammeters, frequency meters, and output meters; and multimeters, vtm's, signal tracers, tube checkers, and other devices help locate the trouble after a breakdown.

In the past, test equipment has played a relatively minor role in the repair of prime equipment. This situation was tolerable as long as prime equipments remained relatively simple; however, the advent of electronics equipments of greater complexity and more exacting tolerances has increased the importance of electronic test equipment which, in turn, has placed a heavy burden of responsibility upon the ET. Because of the shortage of highly skilled electronics personnel, steps must be taken to ease these burdens. One step in the right direction would be to human engineer the test equipments the ET must use, redesigning them to remove limitations which affect the ease with which tasks can be accomplished. Removing such frustrations would do much to improve maintenance of new and complex equipments.

It has been said that test equipment operational and maintenance difficulties originate at the planning table. The contention is that the design engineer anticipates test equipment-user needs, problems, and experience on the basis only of his own training and experience which often is too theoretical. Test equipments must be designed to fit actual field conditions, users, and job requirements.

Not all shipboard electronic test equipment is being used, and for different reasons; first, some ETs have a preference for only certain types of test equipment; second, some ETs avoid using certain test equipments because of difficult-to-operate qualities; third, some test equipments are malfunctioning; and fourth, some ETs do not know how to operate certain types of test equipment.

Some ETs purchase their own electronic test equipment and use it aboard ship. They claim that this equipment is easier to operate, presents a better picture, permits easier adjustment, uses simpler cir-

cuits and therefore is easier to repair. Only about ½ of one per cent of the test equipment on board ship has been purchased by the ET. Nevertheless, it brings up several interesting points. First, that such purchases are merely one method for the release of negative feelings; second, perhaps civilian-type equipment *does* have certain advantages over military-type test equipment; and third, preferences for civilian-type test equipment may be due to the fact that this is *their* test equipment. One other possibility should be considered. Most civilian-type test equipment is more attractive and pleasing to the eye. Further, it generally *looks* delicate and as a result is handled with greater care. Military test equipment *looks* rugged and, perhaps for that reason, receives rougher treatment. It might be unwise to disregard the aesthetics of test instruments in favor of the unattractiveness of plain gray equipment.

KIND OF PERSONNEL USING TEST EQUIPMENT

Over 65 per cent of the test equipment users in the Navy today are 22 years of age, or younger. Electronics technicians at age levels of 25 and above generally plan to make the service a career. By the time an ET reaches the age of 22, he is usually about to terminate his stay in the service.

Almost 60 per cent of the test equipment users have completed schooling through grade 12. Over 35 per cent have completed one or more years of college. In order to obtain admission to an Electronics Class A school a recruit must have a Navy Standard score of 110 on his combined GCT (General Classification Test) and ARI (Arithmetic), and at least a score of 55 on his ETST (Electronics Technician Selection Test). On this basis it might be assumed that an ET has at least an average I.Q., or better. Estimates are that the I.Q. of a graduate of the ET school is at least 108, or better. This fact contributes to the high turnover rate in test equipment-user personnel since most are apt to leave the service for college or technical civilian positions.

Ninety-three per cent of all test equipment users plan to leave the service upon completion of their first enlistment. The result is that just about the time that shipboard personnel reach a level of competence and experience whereby they can operate and use test equipment effectively they are ready to leave the service and will be replaced by less experienced personnel.

TRAINING

"An ET is a technician in name only" . . . so said a Chief Electronics Technician. This statement highlights the popular contention that it takes a great deal more training than currently provided in order to give the ET the electronic background he needs. The present-day ET receives 24 to 26 weeks of training at a Class A school. The actual number of weeks depends upon whether he specializes in either sonar, radar, or communications. At present, the Bureau of Personnel is responsible for the formal training of those men selected for the ET school. Supplementary training is expected to be provided in the form of on-the-job instruction at the station to which the graduate is assigned. Advanced training of a general nature is provided at Class B schools, and instruction on special equipment is given at Class C schools.

The new ET graduate, upon reporting to his assigned station, often discovers that the test equipment provided is not the same as that which he has learned to operate at ET school. This is often true because shipboard type of test equipment must be kept up-to-date with the continually improving prime equipment on board. It is believed that this difficulty is short-lived on the assumption that sufficient transfer of training will take place to assist the ET graduate in learning to use other similar models of test equipment aboard ship.

OPERATIONAL ERRORS COMMITTED BY TEST EQUIPMENT USERS

Electronic technicians do make errors. These errors fall into three general groupings as follows:

a. Substitution-type errors whereby cables, probes, or jacks were placed in the wrong sockets, binding posts, or inserts. These have constituted 53 per cent of the errors made.

b. Omission-type errors whereby settings were omitted. These accounted for 28 per cent of the errors.

c. Reversal-type errors whereby knobs, controls, levers, or charts were turned in the wrong direction. These accounted for the remaining 19 per cent of the errors.

Operational errors occur every day aboard ship with respect to test equipment, e.g., each side of the tube is not checked, the wrong scale graduations are read, or the wrong switch is turned.

Even if the training program is the best that can be provided within the limitations of time, cost, and available personnel, attention should be directed toward designing test equipment which has the lowest possible error potential.

This may be accomplished, in part, by the careful placing of knobs, levers, binding posts, etc. Further care must be taken to minimize the combined number of settings and manipulations required of the operator. When substitution-type errors are possible, special consideration should be given the possibility of color coding. Possibilities of omission and/or reversal-type errors can be reduced by decreasing the number of required settings. Decreasing the error-potential of test equipment is a real money saving proposition for the Navy since many of the errors result in burning out some part of the equipment which calls for expensive repair work.

PARTICULAR SHIPBOARD FACTORS AFFECTING TEST EQUIPMENT

One of the major test equipment problems is the availability of facilities for their stowage. Almost 50 per cent of all test equipment used on board a

destroyer is stored in the ET shack. Twenty-three per cent is located in the store room and consists of rarely used items. Twenty-seven per cent is stored near the prime equipment it is specially designed to be used with, or else it is centrally located because of its greater bulk. In general, the location of test equipment stowage areas is determined by the frequency with which the equipment is used and the location of the prime equipment with which it is most often used. Although most test equipment is found in the ET shack, sometimes it is so "scattered" that the ET himself does not know where any one piece of equipment is located without looking for it first. Stowage then, is a problem and is amplified by the following: the average destroyer in the Fleet carries 62 pieces of test equipment totaling 1,699 lbs. As for volume, 88,181 cubic inches of space is given over to test equipment. In addition, most test equipments have been provided with at least two instruction books. Therefore, the average destroyer has about 124 instruction books weighing a total of 62 lbs.

THE PORTABILITY FACTOR OF TEST EQUIPMENT

How portable should test equipment be? It has been discovered that ETs frequently will not use certain items of test equipment simply because they are too large and bulky to carry. A recent study by the author has shown several interesting factors about test equipment.

With respect to weight, test equipment up to about 12 pounds presented no serious carrying difficulties. Carrying difficulties increased sharply at the 14 lb. level. The question was next considered: "Is the carrying difficulty of test equipment solely a result of weight or is it influenced by *how* that weight is distributed?" Study has shown the following:

Test equipment with a width of 8 inches or less, presented little carrying difficulty. Difficulties increased when the width was greater than 8 inches.

Difficulties encountered due to height of test equipment are essentially the result of floor obstacles. Therefore, it would appear that the tallest floor obstacle on board ship over which test equipment must be carried largely determines the limits of test equipment height. It was determined that test equipment under 18 inches in height presented the least amount of carrying difficulty. Carrying difficulty increased rapidly for equipment taller than 18 inches.

If the equipment is to be straight-arm carried, the bottom of the equipment must clear deck obstacles which, in general, are not over 14 inches above the floor. Further, the average man's knuckle-to-floor measurement is 28 inches and another inch should be subtracted for the distance from the top of the equipment to the carrying handle. Therefore, in order to clear 14 inch obstacles, it would appear that test equipment should not exceed 13 inches in height. On the other hand, the limit indicated earlier was 18 inches. It is believed that of these two dimensions 13 inches should be considered the ideal limit. However, because of certain packaging considerations, 18 inches must be judged the practical limit.

Test equipment with a length of 18 inches or less, presented fewer carrying difficulties than equipment greater than 18 inches.

On the basis of the data derived from the study for length, width, height, and weight of test equipment, it is believed that the maximum acceptable weight should be 14 lbs., maximum acceptable size should be 8 inches wide, by 18 inches high, by 18 inches long. Weight or sizes beyond these limits sharply increase carrying difficulty, or portability of the test equipment.

TEST EQUIPMENT CHARACTERISTICS SUBJECT TO HUMAN ENGINEERING

One of the areas of concern most critical to shipboard test equipment is its maintenance. It is well, therefore, to consider the problem of maintenance of test equipment prior to discussing the human engineering factors related to test equipment.

Electronics technicians do perform maintenance on their test equipment. Although a general feeling prevails that test equipment should not be repaired by other than qualified test equipment repair personnel, ETs indicated that they had done some types of this work.

Electronics technicians generally attempt to repair the test equipment themselves. If they cannot make repairs, the test equipment is sent to a tender or naval repair base, if available. Sometimes partially working, multi-purpose test equipment is retained on board ship because ETs need the function still in operating order and do not want to do without it while the test equipment is in repair.

Most test equipment is repaired by the ETs aboard ship. Almost no entries are made in the records because there are two general feelings:

a. That shipboard ETs are not supposed to repair test equipment. If a record of repair were made, this would be self-admission that the "rule" or "regulation," if any, was not being observed.

b. That many of the repairs were not sufficiently significant to be placed in the record.

The existence of such contentions is unfortunate because it results in valuable information, concerning specific test equipment failures or faults, from ever reaching proper administrative attention. It is likely that such a condition *cannot* be corrected by issuing a regulation to the effect that records *must* be kept of all test equipment repair work performed. However, ETs *are* willing to *talk* about things which they appear unwilling to put in writing. Essentially, the answer may well be the organization of continuous liaison between ETs and Human Engineering personnel for obtaining test equipment repair data through interviews and observation.

THE RELATIONSHIP OF TEST EQUIPMENT DESIGN TO TEST EQUIPMENT MAINTENANCE EXPENSE

The expense of performing maintenance on test equipment can be increased or decreased by the design features of the equipment itself. The following test equipment design conditions have directly influenced the extent of difficulties encountered in test equipment maintenance and therefore have increased repair costs:

Condition not considered by the designer	Result
a. Test equipment when being repaired must often be energized with the outer casing removed.	a. Plugs, jacks, terminals are not made available on inner chassis of equipment. Jury-rigging is necessary to energize the equipment. Man/hours must therefore be spent in jury-rigging instead of test equipment repair.
b. Designer does not provide at least one flat side on which the test equipment can be laid after the cuter casing has been removed.	b. Requires time for setting up a "platform" on which the equipment may be placed to prevent crushing delicate parts.
c. Wiring to a panel does not leave from one edge only.	c. In order to remove panel some wires must be unsoldered. Man/hours are wasted in soldering and unsoldering.
d. Areas are congested with wires.	d. Soldering iron touches wires causing the plastic cover to melt or fuse with other wires.
e. Parts which burn out often are just as difficult to reach as parts which rarely burn out.	e. Man/hours are wasted in dismantling section of the test equipment in order to reach burnt out parts.

Any design within test equipment which restricts the ease with which the equipment can be repaired is going to increase the number of repair man/hours and thereby increase cost of repair. In some cases, it is possible for the cost of repair to equal or exceed the purchase price of the equipment. The following is a list of test equipments which have been repaired, and the costs involved. This list is based upon average costs and average repairs:

Kind	Cost New	Cost of Repair
Multimeter	$ 50.00	$92.00
Voltohmeter Jr.	60.00	46.00
Voltohmeter Sr.	80.00	46.00
Oscilloscope	180.00	92.00
Tube Tester	130.00	92.00
Wavemeter	300.00	46.00
Signal Generator	460.00	92.00

For test equipments bought for $50.00 or under, the cost of first repair usually exceeds the initial price.

Human engineering studies as being carried out by the Human Factors Division of the U.S. Navy Electronics Laboratory at San Diego, California have come up with a number of recommendations for easing the task of the ET as well as easing the expense of test equipment maintenance.

Fortunately, attention is now being given the electronic test equipment problem. Steps are being taken to human engineer test equipment and recognition is being given the fact that test equipment is an essential item in the over-all area of military electronics.

A ship's characteristics demonstrator has been developed for training and demonstration in ship handling exercises. The unit consists of radio-controlled, self-propelled ship models. By means of suitable electronic circuitry, the response of the ship to the helm and to speed changes is designed to give a high degree of realism. The tank in which the ships operate is provided with a model pier, for berthing drill, and with wind and water current generators which can be used at will. The size of the tank corresponds to a 1500 foot square water area. Two models, one single shaft and one twin screw, are provided.

—from "Electronics," September 1957

"ENGINEERING"

VIBRATION AND NOISE OF MECHANISMS AND MACHINES

ACKNOWLEDGEMENT

This article, published in the June 7, 1957 edition of "Engineering," was written by Dr. A. J. King, of the Research Department, Metropolitan-Vickers Electrical Company, Ltd.

PRACTICALLY all types of mechanisms and machines give rise to vibration and noise when they are operating. Until recent years the vibration and noise were regarded as inevitable and even in some cases as an indication of the magnitude of the power involved. It is now realized that both are undesirable from two points of view, that of the machine and that of the operatives and other persons near. As far as the machine is concerned, vibration and noise are nearly always indications of wastage of energy although the amount of power radiated as noise may be only of the order of one watt. The wasted energy is also often accompanied by excessive wear, so on both these counts any excessive vibration and noise deserve very critical examination. The effects on operatives and other persons near may range, in the case of vibration, from a mild irritation to an attack of Raynaud's disease and, in the case of noise, from interference with sleep to partial or complete deafness. It is clear that the problems of vibration and noise from mechanisms and machines call for very serious study as to their causes and methods of avoiding or reducing them, and some aspects of these problems are considered below.

VIBRATION

Units

Most engineers in this country think of vibration in terms of the double amplitude of the movement and they express this in thousandths of an inch, contracted to "thous" or "mils." The more mathematically inclined prefer to use the single amplitude and quote it as "plus and minus so many thous." This use of amplitude has probably arisen partly due to the early methods of measurement and partly to the engineer's continual concern with permissible clearances and stresses. However, where the radiation of noise from a vibrating surface is involved, the magnitude of the oscillatory velocity of the surface in a direction normal to its plane is much more important than the amplitude, since, with the area of the surface, it defines the "strength of the source" of sound. As has been pointed out,[1] there is something to be said for adopting 5×10^{-6} cm. per sec. or 2×10^{-4} in. per sec. as the unit of vibration velocity where sound radiation is concerned, but the late H. G. Yates and the writer did not receive general support for this unit. It is also convenient where sound radiation is concerned to express the velocity on a decibel scale by which in terms of 10^{-6} cm. per sec., an oscillatory velocity of v cm. per sec. r.m.s. becomes 20 log $(v \times 10^6)$ db. Bruel [2] has suggested a similar scale based on a threshold velocity of 0.0312 cm. per sec., irrespective of frequency, his vibration units for a velocity of v cm. per sec. being $20 \log\left(\frac{v}{0.0312}\right)$. He calls these units "pal."

When the consequences of a vibration are dependent on acceleration, it is usual to adopt as a unit the acceleration due to gravity, approximately 386 in. per sec. per. sec. or 981 cm. per sec. per sec. This situation arises, for example, when a system receives an impulse and the forces involved are determined by the mass and acceleration of the parts of the system concerned. Table I illustrates the magnitudes involved.

Subjective Response

The subjective response of human beings to vibrations of different frequency and amplitude has been studied by several investigators, [3,4,5], and Postlethwaite [6] has attempted to reduce the available information to a set of curves corresponding to typical levels of vibration sensation. These curves indicate that at one cm. per sec. the human body is acceleration-sensitive, 0.12 in. per. sec. per sec. or $3.1 \times 10^{-4}g$ being the threshold and 1.2×10^{2} in. per sec.

per sec. or 3.1g intense vibration, while at 10 cm. per sec. the response is related more to velocity, the corresponding acceleration limits being 1.2 in. per sec. per sec. for threshold and 1.2×10^2 in. per sec. per sec. for intense vibration. The above determinations were carried out on a small number of subjects so, until further tests are made on many more subjects, covering sex, age and method of application, the results quoted should be regarded as approximate only.

Measurement

The early methods of measuring vibration amplitudes, involving falling smoked glass plates or rotating smoked cylinders, gave way to recording on paper tape or scratching on cellulose tape with subsequent optical amplification. These methods, which depend on having a fixed reference point, are still used at low frequencies where amplitudes are comparatively large, but they have been supplemented by more modern methods,[1] mostly electronic, although some are direct-reading without amplification. A big advantage of the modern methods is that it is no longer necessary to have a fixed reference point, as small mechanical-electrical transducers, or "pick-ups," are available for attaching to vibrating parts to measure the absolute vibration without reference to a fixed point. Many of these transducers are piezo-electric accelerometers, the piezo-electric element generating a voltage proportional to the force required to accelerate a known mass. Others are of the moving-coil type in which either the permanent magnet or the moving coil is supported flexibly so as to create a more or less fixed reference point in space. These two types of transducer, giving voltages proportional, respectively, to acceleration and velocity, account for most of the vibration measuring pick-ups used in practice but there are a few others[1] which depend on resistance strain gauges, changes in reluctance of a magnetic circuit and changes in capacitance of an air gap. The calibration[1,7] of these vibration measuring devices is usually effected by vibrating tables or beams, the vibration of which has been determined by optical or moving-coil means. However, in some cases, it is possible and convenient to calibrate two pick-ups bolted together by reciprocity technique.[8,9] This is particularly so at high frequencies where other methods are difficult. A further important advantage of electronic methods of measuring vibration is the ease with which the motion can be analyzed[1] into its components, thus facilitating the diagnosis of the causes of these components and the specification of remedial measures.

NOISE

Units

Noise is defined[10] as "sound which is undesired by the recipient," so a statement of the magnitude of a noise must cover the subjective aspect of its being "undesired" as well as the objective aspect of a sound wave. The latter is readily specified in terms of the oscillatory pressure in the wave above and below the mean atmospheric pressure, the unit being the dyne per sq. cm. To form a convenient scale of magnitude, a reference pressure of 0.0002 dyne per sq. cm. r.m.s., which is near to the minimum audible, or "threshold," pressure at a frequency of 1,000 cycles per sec., has been chosen. Since the range of sound pressures to which the human ear responds is so large, roughly 10^6:1, and for reasons associated with the law of the ear's response, a logarithmic scale has been adopted. On this scale a sound of p dynes per sq. cm. r.m.s. has a sound pressure level of

$$20 \log \frac{p}{0.0002} \text{ decibels.}$$

Subjective Response

The scale of subjective response is complicated by the variation in sensitivity of the human ear with frequency. This variation has been studied by a number of investigators and three sets of equal loudness curves have been produced[11,12,13] of which the most recent[13] determined at the National Physical Laboratory, is probably the most representative. For comparisons of loudness of tones the sensitivity of the ear at 1,000 cycles per sec. was adopted as a reference standard at Paris in 1936 and, subject to certain conditions of listening,[10] the decibel scale of sound pressure level at this frequency became the phon scale of equivalent loudness, or loudness level, the units being called "phons." Noises of any degree of complexity are also referred in the same way by aural comparison to the equally loud tone of 1,000 cycles per sec. In this way, by using a relative instead of an absolute scale, the difficult, if not impossible, task of "measuring" subjective responses is avoided.

While the phon scale provides a common basis for rating the loudness of steady sounds of all compositions, the numbers attributed to sounds of different loudness do not agree in relative magnitude with the relative magnitude of the loudness sensations induced in average individuals. The problem of deriving a true loudness scale has been studied by a number of investigators[11,16,17,18] each group producing a somewhat different scale. However, they are in rough agreement that, over the practically important range from 40 to 100 phons, the loudness of a sound is judged by the average individual to be doubled when its equivalent loudness is increased by approximately 10 phons. This value was therefore agreed upon at a recent international meeting in Paris and it is expected to form the basis of a new loudness scale. The units of the scale are arbitrary but it was agreed to make unit loudness that of a sound of 40 phons since this value has been used as a standard in subjective measurements of pitch. The units are called sones and the loudness, L, of a sound of P phons is given by this scale as $L = \text{antilog } (P-40)\ 0.03$ sones. While this relation has the merit of simplicity it is approximate only and may be modified slightly in due course by national and international agreement.

As regards intermittent or varying sounds, the

B.S.I. has not issued any recommendations beyond the reliance on aural balance with a reference tone of 1,000 cycles per second laid down in B.S.S. 661 for steady sounds.

Measurement

The determination of the physical magnitude of a sound wave is usually a straightforward measurement with a microphone, amplifier and indicating instrument. This apparatus can be calibrated [14] to read in sound-pressure level and weighting circuits can be included to imitate the pure tone response of the ear at typical levels, usually 40 db, 70 db and over 80 db which has a "flat" response. Such equipment with an r.m.s. instrument scaled in decibels is called a "Sound Level Meter" and many are in use in Britain, the United States and other countries in compact portable form. While they may read correctly in phons for pure tones, they tend to read low, by up to 10 or more phons, on complex noises for reasons which have been discussed.[15] Alternatively, the apparatus can be fitted with filters which permit the noise spectrum to be analyzed into bands of various widths, usually of full, half or one-third octave, or so narrow as to select discrete components. This technique of analysis is again, as with vibration, of great assistance in diagnosing the cause of a noise and in specifying remedial measures as discussed later.

If it is important to have the equivalent loudness of a noise in phons by an objective as opposed to a subjective [12] method it is possible to derive it from an analysis by summation of the contributions of the components. An instrument to carry out this summation has been developed [15] but, although it gives results which accord closely with those given by the fundamental reference tone technique [12] for many practical noises having discrete components, it tends to read low, in phons, although not as low as the sound level meter, on noises having a continuous spectrum covering wide bands of frequencies.

COMMON CAUSES OF VIBRATION

Unbalance

When an anchored mechanism is out of balance, either in oscillation about a point in a straight line or in rotation about an axis, external reaction or restraining forces are called into play to oppose the internal unbalanced or mass-acceleration forces. Since the surrounding bodies or foundations are not infinitely stiff, some oscillatory movement of the anchoring points is inevitable and this constitutes vibration. If the stiffness at the anchoring points is negligibly small, the unbalance forces are all available for shaking the mechanism. In general, the mechanical impedance of the anchoring points is complex and has to be taken into account, although, at particular frequencies, mass and stiffness reactances may nullify each other leaving only dissipative forces to constrain the system at these resonant frequencies. Unbalance forces usually have frequencies corresponding to the revolutions or oscillations per second of the system, or the low order harmonics, so usually they do not exceed 100 cycles per second.

Cyclical Irregularities

In many mechanisms and machines the driving and load forces are not constant but are intermittent or change suddenly, as, for example, in piston engines, gears, pumps and electric motors. In rotating machines the frequencies of these cyclical irregularities are determined by the revolutions per second multiplied by the number of impulses per revolution, as, for example, in the cases quoted, the number of firing strokes, gear contacts, pump discharges and rotor slots. In the case of gears there are often other irregularities corresponding to the number of teeth on the table of the machine on which the gears were cut and in the case of alternating-current motors the slot note can be modulated by twice the supply frequency.

Rolling and Sliding Contact of Hard Surfaces

Small irregularities in the surfaces of metals in unlubricated rolling or sliding contact give rise to appreciable vibration even when the surfaces appear to be relatively smooth to the touch. If, in the case of sliding contact, there is intermittent "stiction," or welding and tearing, known generally as "slip-stick," the ensuing vibration may have a pronounced frequency, like the squeak of a brake, determined largely by the friction, mass and stiffness of the parts in contact. Otherwise, the vibration is likely to contain all frequencies more or less equally, depending on any local accentuation by resonances.

Impacts

A regular succession of impacts, such as is given by a pneumatic hammer or chipper, constitutes a vibration of a frequency corresponding to the number of impacts per second together with a train of harmonics due to its non-sinusoidal character. However, the impacts can shock-excite mechanical systems which are capable of vibrating, such as panels, at their natural frequencies, producing trains of damped oscillations and one of the harmonics may even excite part of the system to resonance, giving rise to an increased vibration of that frequency.

COMMON CAUSES OF NOISE

Vibrating Surfaces

Any surface which is vibrating in a direction normal to its plane radiates sound waves of a frequency corresponding to that of the vibration. If the linear dimensions of the surface are large compared with the wavelength in air, $\lambda = \frac{1{,}100}{f}$ ft. or $\frac{33{,}400}{f}$ cm. where f is the frequency in cycles per sec. and all points on the surface are vibrating in phase, the air near the surface follows the movement of the surface and plane waves are radiated having a sound pressure $p = 42\ v$ dyne per sq. cm. where v is the oscillatory velocity of the air and surface in cm. per sec. The velocity corresponding to the reference pressure of 0.0002 dyne per sq. cm. is therefore 5×10^{-6} cm. or 2×10^{-6} in. approximately. Vibration amplitudes, velocities and accelerations corresponding to sound pressure levels of 0, 60 and 120 db under the above

TABLE I.—*Vibration Magnitudes*

Corresponding sound pressure level, db	Oscillatory velocity, in. per sec. r.m.s.		Frequency, cycles per sec.				
			1	10	100	1,000	10,000
0	2×10^{-6}	Amplitude, in. ±	4.5×10^{-7}	4.5×10^{-8}	4.5×10^{-9}	4.5×10^{-10}	4.5×10^{-11}
		Acceleration, g ±	4.6×10^{-5}	4.6×10^{-7}	4.6×10^{-6}	4.6×10^{-5}	4.6×10^{-4}
60	2×10^{-3}	Amplitude, in. ±	4.5×10^{-4}	4.5×10^{-5}	4.5×10^{-6}	4.5×10^{-7}	4.5×10^{-8}
		Acceleration, g ±	4.6×10^{-3}	4.6×10^{-4}	4.6×10^{-3}	4.6×10^{-2}	4.6×10^{-1}
120	2	Amplitude, in. ±	4.5×10^{-1}	4.5×10^{-2}	4.5×10^{-3}	4.5×10^{-4}	4.5×10^{-5}
		Acceleration, g ±	4.6×10^{-2}	4.6×10^{-1}	4.6	46	460

conditions of plane wave radiation are given in Table I. If the dimensions of the vibrating surface are small compared with a wave length, and air circulation between front and back is prevented, for example, by enclosure, a frequency term enters into the expression for the radiation, and the sound pressure at a distance where the radiation has become spherical tends to follow the acceleration of the surface. If the area of the surface is A sq. cm., ρ the density of air = 0.0012 gramme per c.c., and x the distance in cm. from the surface where the radiation has become spherical, the sound pressure is: —

$$p = \rho \frac{v A f}{x} \text{dyne per sq. cm.}$$

At distances, intermediate between these two extreme cases, interference effects occur and each case needs individual consideration.

Sources of vibration have been discussed above.

Repeated Puffs of Gas

Examples of pulsating air streams producing noise are to be found in fans, compressors and internal combustion engines. The oscillatory velocity of the air particles is often superimposed on the mean velocity of the air stream, but expressions similar to those quoted in the previous paragraph still give the sound pressure close to the source and at a distance x cm., large compared with the dimensions of the source in terms of the oscillatory component, v cm. per sec., of the velocity at the source and the area, A sq. cm., of the source.

High-Velocity Gas Streams

Although a gas stream may not be obviously discontinuous it usually has turbulence and vortices which can be responsible for very loud noises. In free space, a vortex is a closed circulatory system but when it breaks on an obstacle pressure waves are produced. Trains of vortices at regular intervals can thus produce musical notes,[19] such as the Aeolean tones from telephone wires in a breeze, and turbulence can produce noises containing all frequencies, so-called "white noise," like the roar of a jet engine exhaust.

REDUCTION OF VIBRATION AND NOISE

When it has been established that a machine is making too much vibration or noise it becomes necessary to consider the available remedial measures. The trouble may be due to some defect or bad design in the machine itself, or it may be due to some fault or lack of forethought in the installation. Both these possibilities must be given careful consideration to ensure that a result which is technically, economically, and, if necessary, aesthetically satisfactory is achieved.

Reduction at the Source

The most helpful information in attacking the disturbance at its source is an analysis giving the frequency and magnitude of the components. This information is readily obtainable by means of a suitable transducer, amplifier and analyzer as previously discussed. Components having definite frequencies can often be allocated to their respective sources from a knowledge of the mechanical or electrical particulars of the machine; with rotating machines, for example, dividing the frequencies of the components by the revolutions per second gives a series of numbers which may include the number of gear teeth, fan blades and armature slots, so giving positive identification of the sources of the respective components. Reduction of the fundamental rotational component is usually a matter for improved balance, and sensitive apparatus for detecting the magnitude and phase of residual unbalance has been described.[20] The ways in which gear errors, due to both the teeth of the cutting table and the profiles of the mating teeth, can be reduced by grinding, scraping and shaving, have been discussed [1,21,22] and substantial improvements have been effected in some cases. In particular, a resonance of the gear wheel has accentuated the tooth contact note at normal speed and necessitated a change to a different number of teeth.

It is often found that a substantial part of the noise or vibration of a gear consists of components which cannot be attributed to any particular feature of the gear, and of bands of frequencies so closely spaced as to be virtually unresolvable. Similar unrelated frequencies and bands are encountered in machines fitted with ball or roller bearings and it is felt that these two cases of gears and rolling bearings have a common feature of fundamental importance, namely, the contact of metal surfaces either rolling or sliding on each other. Even though these surfaces have been carefully ground, asperities of the order of 10^{-4} in. are inevitably present and will cause corresponding vibrations of the two surfaces relative to each other. Reference to Table I shows that such

vibrations at medium and high frequencies can cause very loud noises. If, however, the two surfaces are separated by an oil film thicker than the asperities, solid contact is avoided and so is the relative vibration from this cause. It is difficult to guarantee the existence of such an oil film in the cases of gears and rolling bearings since the requisite conditions for hydrodynamic lubrication do not always exist there as they often do in the case of lubricated sleeve bearings. It has therefore been proposed to fill up the valleys in the metal surfaces with "Teflon," but no information as to the success of this method is available. Where welding and tearing take place at the contact region, the extent to which the two metals alloy with each other is felt to be important. There is an obvious need for extensive investigational work in this field.

As mentioned above, some vibration and noise may arise from fans and electrical machinery and analyses will usually indicate the features responsible. In the case of fans, balance, blade design, clearance between runner and case and the excitation of natural modes of vibration of ducting by turbulence are all important factors and may need reconsideration. Appreciable improvements can be effected by damping the flat metal sheets forming air ducts so that their "ringing times" when impulse excited by turbulence are very much reduced. Two methods of achieving increased damping have been found effective. The first is to build the duct out of two-ply sheets of thinner gauge metal lightly fastened together by rivets and the second is to apply to the walls of the duct a layer of viscous material such as bituminized felt [23] or a resin-bonded compound [24] sprayed on to a thickness about twice that of the metal. In both cases, vibration of the sheet dissipates energy either in interlaminar friction or by viscous forces, so avoiding sustained vibrations which increase the noise in the air stream. The noise from the pulsating exhausts of internal-combustion engines can be reduced by smoothing out the pulsations and so making the exhaust gases into steady streams. This is effected by a low-pass filter consisting essentially of a receiver and an exhaust or "tail-pipe." The dimensions of the receiver and tail-pipe must be chosen so that the reactance of the former is much less than that of the latter at the frequency of the pulsations, the ratio of the two reactances being an indication of the attenuation. The reactance of a receiver of volume V ccs. at a frequency of f cycles per sec. is $X_v = \frac{\rho c^2}{2\pi f V}$ where ρ is the gas density in grammes per c.c. and c the velocity of sound in the gas in cm. per sec. The reactance X_t of a tail-pipe of length l cm., short compared with a wavelength, and cross section s sq. cm., is

$$X_l = \frac{2\pi f \rho l}{s}$$

If $X_t \gg X_v$ the attenuation is given by

$$A = \frac{X_l}{X_v} = \frac{4\pi^2 f^2 l V}{c^2 s}$$

or in decibels by 20 log A db.

This very much simplified theory of the single-stage silencer as fitted to automobiles is sufficient to indicate the roles played by the receiver and tail-pipe. In practice, receivers are often fitted with baffles to make multiple stage filters and alternative paths of different lengths are sometimes provided in attempts to achieve noise reduction by interference.

In electrical machines the slot note is usually the most important component in both vibration and noise. In direct-current machines it can be reduced by skewing armature slots, semi-closing them and grading air gaps, each of these three steps being capable of giving a reduction of 10 db or to roughly one-third amplitude. In alternating-current machines with distributed windings, the numbers of rotor and stator slots and the harmonics they introduce have to be carefully chosen [25] so as not to excite pronounced natural modes of vibration of the stator and frame. Owing to the complexities and uncertainties of the factors involved, it is often necessary to proceed step by step in the direction indicated by theory and to make an analysis at each stage to check the magnitude of the change effected and so to proceed with more certainty to the next step if further reduction is required.

INSTALLATION EFFECTS

In a great number of cases the vibration and noise of machines are needlessly increased by installation conditions. For example, machines with large oscillating or unbalanced rotating masses are often installed on the second or higher storeys of buildings with the result that excessive vibration is experienced throughout the building. In some cases the vibration is increased so as to be unbearable by resonance of the floor on which the machines stand. It is obviously better to install such machines on solid ground, preferably with an air gap several feet deep round the base. Alternatively, and, in difficult cases, in addition, the vibrating machine may be mounted on resilient supports which can be designed [1] to transmit only a fraction of the vibration to the building.

FOUNDATIONS

The use of a large foundation block resting on resilient mountings can reduce the vibration of a machine, or group of machines, by increasing the total connected mass. Such a block or steel frame is almost essential when supporting coupled machines resiliently as the group is then self-contained and free from relative movements. It is also very helpful with tall machines in that the base can be broadened, so reducing the tendency of the machine to rock on the resilient mountings. When a foundation block is sunk in the ground it is preferable to leave an air space all round the sides rather than to fill it with resilient material such as cork. It is also convenient

to bring the mounting resilient material up to floor level rather than to have it under the block where replacement would be difficult. The block is then hung on cross beams passing through it near the top. This arrangement has the additional advantage that the center of gravity of the supported system is usually approximately in the plane of suspension, thus leaving the vertical and rocking modes uncoupled. An excellent review of resilient mountings has been given by J. A. Macinante.[26]

Whenever resilient mountings are used it is important to ensure that their effectiveness is not materially reduced, or even cancelled, by solid connections such as pipes, cables, earth straps and holding-down bolts. The latter, if used, should have resilient washers and bushes, but in many cases holding-down bolts are not necessary or desirable. It has been shown [1,27] that rubber is very suitable for resilient mountings and that some materials,[28] such as felt, are liable to have a very high ratio of dynamic-to-static stiffness and so to be correspondingly inefficient in attenuating vibration. A warning should also be given regarding the dynamic performance of leaf springs which, due to inter-lamina friction, have been known [29] to have a dynamic-static stiffness ratio of 30 for small amplitudes of vibration insufficient to cause sliding of the laminae. This trouble can be avoided by inserting thin sheets of soft rubber between laminae.

When noisy machinery is installed in the open air, it may be possible to take advantage of the attenuation of noise with distance. This attenuation is usually only a few decibels up to a distance roughly corresponding to the linear dimensions of the major noise-emitting surface or opening but thereafter it approximates to a reduction of 6 db for every doubling in distance. Inside an enclosure this attenuation with distance is limited by reflections from the walls which conserve the sound energy and cause an increase in sound level compared with freespace conditions. With hard bare walls this increase may amount to 5 or 10 db depending on the total sound absorption present. If, therefore, sound absorption is introduced into an enclosure the "build-up effect" may be reduced and the free space level approached. In both the above cases, by distance and absorption, the law of decreasing returns operates very quickly to limit the improvement that can be obtained in practice.

TRANSMISSIONS

Vibration of most building materials occurs, with little attenuation so the vibration of machines in buildings should be prevented from reaching the structure. As indicated in the previous section, this can be done by using resilient mountings and by introducing discontinuities such as air gaps round foundation blocks and "breaks" of building felt round sections of concrete floors.

The reduction of air-borne sound in transmission is usually effected by some form of enclosure. If M lb. per sq. ft. is the surface density of the enclosing wall, the attenuation at a frequency of f cycles per sec. where the stiffness is negligible should theoretically be given by

$$\text{attenuation} = 20 \log Mf - 29 \text{ db.}$$

Investigations which were made at the N.P.L. have shown [30] that the values obtained in practice are somewhat lower, more realistic values being given by the relation

$$\text{attenuation} = 15 \log Mf - 21 \text{ db.}$$

Enclosures made of porous material, such as rock wool, can be used, but the attenuation in decibels is proportional to thickness and to get 30 db at medium frequencies calls for a thickness of the order of 1 ft.[31] and more at lower frequencies.

When the air-borne noise of a machine has been confined by a solid enclosure it becomes important to have the machine on resilient mountings, if not already so mounted, as otherwise the attenuation of the enclosure may be lost by conduction of vibration from the machine to the enclosure, from which it would be radiated as noise. The two attenuations of air-borne and structure-borne noise should be coordinated so as to avoid waste. The simplest enclosure is often a brick-walled concrete-roof type with no windows and a heavy door and such a construction can readily give attenuations of 30 db or more at medium and high frequencies. If it is essential to have windows, high attenuations can still be achieved [32] by making them of heavy plate glass and having two or more well spaced and separately mounted to avoid coupling. If lower attenuations are adequate, some form of steel framing filled in with panels of asbestos cement or similar material may provide a cheaper but effective alternative.[33] A little sound absorption inside is helpful but complete lining with sound-absorbing material is seldom justified.

As a result of enclosure it may be necessary to provide arrangements for cooling. If liquid cooling is used the liquid can be taken through flexible coupling pipes to the outside and cooled there, the flexible sections of pipe being necessary to avoid conduction of vibration to the enclosure. With air cooling, inlet and outlet ducts of adequate section must be provided and fitted with sound-attenuating systems to avoid the escape of too much noise. Data are available [34] for designing "splitter" type silencers to give any required attenuation of noise of specified frequency composition, provided that roughly half the duct cross-section can be sacrificed to be taken up by the splitters. This information is also available for designing silencers for any high-velocity gas streams, such as engine exhausts. If the frequency range is very wide, as in jet engines, there is much to be said for a two or more stage filter of the straight-through splitter type [35] which can be designed for low back-pressure.

GEARBOXES

A special case of enclosure is provided by gearboxes, although the principles involved are applicable to other cases of noisy machines coupled by shafts to other machines. The essential point is that

the vibrations associated with the operation of gears are conducted both through the bearings to the case and through the shafts to other machines. It is therefore not sufficient to enclose the gearcase alone if quiet operation is essential. It is then necessary to interpose flexible couplings between the gear and other machines, preferably inside the noise reducing enclosure so that the only shafts coming out of the enclosure are relatively free from vibration. There are several ways in which this can be done [36] but it is difficult to avoid some increase in weight and dimensions as the price of reduced noise.

In order to demonstrate the substantial noise reductions which can be effected by this combination of resilient mounting and enclosure and also to show the prime importance of dealing adequately with both these measures and the futility of dealing with only one, a small gear was enclosed within a steel gearbox. Flexible couplings were included in the input and output shafts and the gearbox was resiliently mounted inside the half-inch steel enclosure. Provision was made for short-circuiting the flexibility of the couplings and the resilience of the mountings, and also for quickly removing the ¼ inch thick steel cover of the enclosure. A driving motor and a generator were coupled to the input and output shafts and the load fixed at 1.25 kW. In view of the noise from the motor and generator, it was necessary to pick out the gear noise by an analyzer, the principal components being the tooth contact note with its second and third harmonics. The results of the noise measurements are given in Table II, while the

TABLE II—*Noise Analyses of Tooth Contact Components*

Microphone 18 in. from center of gearbox.
Input 1.25 kW. I.L.—Intensity level db

Frequency, cycles per sec.	A Solid with cover off, I.L. db.	B Solid with cover on, I.L. db.	C Resilient with cover off, I.L. db.	D Resilient with cover on, I.L. db.	Component
					Tooth contact
1,100	85	84	76	49	Fundamental
2,200	80	76	77	50	2nd harmonic
3,300	82	65	70	44*	3rd harmonic

*Background

corresponding values of equivalent loudness of the gear noise as deduced from a loudness summation [11,15,37] of the three components are given in Table III. It is seen that, in this case, enclosure and resili-

TABLE III—*Loudness Summation of Tooth Contact Components, Equivalent Loudness (Phons)*

A Solid with cover off, E.L. Phons	B Solid with cover on, E.L. Phons	C Resilient with cover off, E.L. Phons	D Resilient with cover on, E.L. Phons
91	87.5	87	63

ence separately give reduction of only 3 or 5 phons but together they give 28 phons. The precise values will vary in different cases depending on the relative magnitudes of air-borne and structure-borne contributions to the noise, but it is clearly important to give adequate consideration to both in order to avoid disappointment and wasted effort.

CONCLUSIONS

It has been shown that the solution of problems involving the reduction of noise and vibration of mechanisms and machines calls for a broad appraisal of the factors contributing to the disturbance and a critical assessment from the utilitarian, economic and aesthetic points of view of the various methods available for effecting improvements. In some cases changes in design or materials may be indicated but in others the use of a standard machine together with adequate measures to localize the disturbance may be a better all-round solution. An important gap in the present fundamental knowledge of the generation of vibration concerns the rolling and sliding contact of hard metals and as this problem concerns such important mechanisms as ball bearings and gears, it calls for urgent consideration on the part of competent research organizations.

REFERENCES

1. King, A. J. "Analysis of Vibration Problems," *J.I.E.E.*, vol. 93, Part II, No. 35, page 435, (1946).
2. Bruel, P. V., *Sound Insulation and Room Accoustics*, Chapman and Hall, page 169 (1951).
3. Knudson, V. O., "Hearing with the Sense of Touch," *J. of General Psychology*, vol. 1, page 320 (1928).
4. Meister, F. J., "Die Empfindlichkeit des Menschen gegen Erschutterungen," *Forschung*, Edition A, page 116 (1935).
5. Bekesy, G. von, "On Vibration Perception," *Akustische Zeitschrift*, page 316 (1939).
6. Postlethwaite, F., "Human Susceptibility to Vibration," *Engineering*, vol. 157, page 61 (1944).
7. Maguire, C. R., "The Development and Calibration of Quartz Accelerometers," *V.D.I. Berichte Bd.* 8, pages 152 to 155 (1956).
8. Trent, H. M., "The Absolute Calibration of Electro-Mechanical Pick-ups," *J. App. Mech.*, 15 (i), page 49, (March, 1948).
9. Morrow, C. T., "Reciprocity Calibration of Vibration Probes," *J. Acous. Soc. Am.*, vol. 20, No. 6, page 826 (Nov., 1948).
10. B.S.I., "Glossary of Acoustical Terms," B.S. 661 (1955).
11. Fletcher, H., and Munson, W. A., "Loudness, Its Definition, Measurement and Calculation," *J. Acoustical Soc. Am.*, vol. 5, page 82 (Oct., 1933).
12. Churcher, B. G., and King, A. J., "The Performance of Noise Meters in Terms of the Primary Standard," *J.I.E.E.*, vol. 81, page 57 (July, 1937).
13. Robinson, D. W., and Dadson, R. S., "A Redetermination of the Equal Loudness Relations for Pure Tones," *Brit. J. App. Phys.*, vol. 7, pages 166 to 181 (May, 1956).
14. King, A. J., and Maguire, C. R., "The Pressure and Field Calibration of Microphones," *Acustica*, vol. 3, page 123 (1951).
15. King, A. J., Guelke, R. W., Maguire, C. R., and Scott, R. A., "An Objective Noise Meter Reading in Phons for Sustained Noises," *J.I.E.E.*, vol. 88, Part II, No. 3, page 163 (June, 1941).
16. Churcher, B. G., King, A. J., and Davies, H., "The Measurement of Noise with Special Reference to Engineering Noise Problems," J.I.E.E., vol. 75, No. 454, page 401 (Oct., 1934).
17. Robinson, D. W., "The Relation Between the Sone and Phon Scales of Loudness," *Acustica*, vol. 3, No. 5, page 344 (1953).
18. Stevens, S. S., "The Measurement of Loudness," *J. Ac. Soc. Am.*, vol. 27, No. 5, pages 815 to 829 (Sept., 1955).
19. King, A. J., "The Reduction of Noise from Air-conditioning Systems," *Engineering*, vol. 157, page 501 (1944).

20. Rushing, F. C., and Rose, B. A., "Balancing Rotating Machines in the Field," *Electric Journal*, vol. 34, page 441 (Nov., 1937).
21. Dorey, S. F., and Forsyth, G. H., "Some Gear Cutting Inaccuracies and Their Effect on Gear Loads and Gear Noises," *Trans. N-E Coast Inst. Engrs. Shipblders.*, vol. 63 (6), page 267 (1947).
22. White, B. A., "Suppression of Noise in Gears," *Power Transmission*, vol. 15, page 379 (April, 1956).
23. Geiger, P. H., "Noise Reduction Manual," Michigan and Oxford University Press (1955).
24. Oberst, H., "Damping of Vibrations in Sheet Metal," *Akustische Beihefte*, vol. 4, page 181 (1952).
25. Alger, P. L., "The Magnetic Noise of Polyphase Induction Motors," Power App. and Systems, *A.I.E.E.*, page 118 (April, 1954).
26. Macinante, J. A., *Vibration and Shock Isolation*, Technical Paper No. 7, Australian National Standards Laboratory.
27. Jackson, R. S., King, A. J., and Maguire, C. R., "The Determination of the Static and Dynamic Elastic Properties of Resilient Materials," *I.E.E. Proc.*, Part II, vol. 101, No. 83, Oct., pages 512 to 521 (1954).
28. King, A. J., "The Reduction of Structure-Borne Noise by Vibration-Attenuating Supports," *Engineering*, vol. 144, page 296, 1937; vol. 146, pages 124 and 193 (1938).
29. King, A. J., "Attenuation of Vibration by Leaf Springs," *Engineering*, vol. 178, page 856 (1954).
30. Aston, G. H., *The Sound Insulation of Partitions*. H.M.S.O. (1948).
31. King, A. J., "The Measurement and Reduction of Noise," *M-V Gazette*, page 153 (Sept., 1947).
32. King, A. J., "Reducing Engine Noise at Ashford Common Pumping Station," *Engineering*, vol. 183, pages 16-17 (1957).
33. Harper, G. B., Glover, S., and Brownsey, C. M., "Transformer Noise Limitation." C.I.G.R.E., Paris, 1956, Paper 108.
34. Brittain, C. P., Maguire, C. R., Scott, R. A., and King, A. J., "Attenuation of Sound in Lined Air Ducts," *Engineering*, vol. 165, pages 97 and 145 (1948).
35. King, A. J., "Silencing a Turbo-Jet Engine House," *Engineering*, vol. 183, page 142 (1957).
36. Pat. Application, Nos. 23586/53, 25335/53 and 17268/54.
37. Stevens, S. S., Calculation of the Loudness of a Complex Noise," *J. Ac. Soc. Am.*, vol. 28, No. 5, pages 807 to 832 (Sept., 1956).

U. S. Navy tests on two 500 horsepower gas turbine engines have indicated a high degree of operational reliability. The engines were subjected to a 1500 hour service test to determine their reliability and to obtain maintenance data. Only minor inspection and maintenance operations were carried out during the tests, and the engines remained in good operating condition at the completion of the test schedule. A definite advantage in overhaul costs over conventional internal combustion engines is indicated. The service application of these particular engines is in powering sweep gear aboard Navy minesweepers.

HILBERT SCHENCK, JR.

CORRELATIONS RELATING HEAT TRANSFER AND PRESSURE DROP IN COMPACT HEAT EXCHANGERS

THE AUTHOR

was born in Boston, February 12, 1926. Attended primary schools in the New England area and served two years in the Navy during World War II as an electronic technician. Attended Williams College in Williamstown, Massachusetts for four years receiving a B.A. degree, then Stanford University for two years receiving an M.S. in Mechanical Engineering. Employed for four years by Pratt and Whitney Aircraft, East Hartford, Connecticut as a test engineer in the nuclear propulsion for aircraft project. Joined the staff of Clarkson College in the fall of 1956 as an Assistant Professor of Mechanical Engineering. Author of several books and papers on underwater visibility, photography, and diving.

INTRODUCTION

The increasing use of gas turbine power in ships, aircraft, and in central stations has also focused attention on the design of compact heat transfer equipment associated with such power units. In the case of a ship or aircraft, the thermal efficiency of a gas turbine engine can be increased and the unit size decreased through the proper use of compact, regenerative heat exchangers.[1] Such an application permits the transfer of thermal energy from gases downstream of the turbine to unburned gas about to enter the combustion chambers. The operation of gas turbine cycles by nuclear power will undoubtedly result in even more research into the design and fabrication of compact heat transfer apparatus.

Mobile gas turbine units, whether at sea or in aircraft are necessarily restricted in size, and the thermal engineer is thus constantly striving to reduce the volume of his heat exchangers. But reduced size usually means greatly increased pressure drops imposed on the gases passing through the unit, since compactness in exchangers is generally associated with small passages, grooved, waved, or interrupted fins, and high fluid velocities. Pressure drop may often become as important a consideration to the engineer as the heat transfer coefficient, and he must often balance one against the other to arrive at a suitable exchanger. Thus the relative gain in compactness and ease of heat transfer must be weighed against the relative loss in pressure, or, in the nomenclature of this paper, the relationship between the heat transfer "J' and the friction factor (f) must be known. The purpose here is to show that a general relationship between these two primary quantities does exist, and that this relationship sets a limit on compact heat transfer surface performance.

NOMENCLATURE

Letters

- C_p — specific heat at constant pressure, Btu/lb_m, F
- f — Fanning friction factor, dimensionless
- G — fluid mass velocity, $lb_m/hr, ft^2$
- h — heat transfer coefficient, Btu/(hr) (ft^2) (F)
- k — thermal conductivity, Btu/(hr) (ft) (F)
- r_h — hydraulic radius, ft
- μ — viscosity, lb_m/ft-hr
- ρ — mass density, lb_m/ft^3

Groups

- J — Colburn or heat transfer factor = $N_{st}\ N_{pr}^{2/3}$
- N_{pr} — Prandtl number = $(\mu C_p)/k$
- N_r — Reynolds number = $(4\ r_h\ G)/\mu$
- N_{st} — Stanton number = $h/G,C_p$

THEORETICAL ANALOGIES RELATING f AND J

There have been a number of attempts to draw an analogy between the mechanism of heat transfer through a boundary layer and that of frictional losses suffered by a fluid as it passes the walls of a conduit.[2]

The most well known is "Reynolds Analogy," based on the assumption that the Prandtl Number of the fluid was unity and that the entire fluid regime was turbulent so that both heat transfer and momentum were transferred by eddy mixing as well as by molecular conduction. From such assumptions Reynolds derived

$$N_{st} = h/G,C_p = f/2 \quad \ldots\ldots\ldots (1)$$

Colburn,[3] after examining experimental data on forced convection heat transfer in tubes proposed

$$J = N_{st}\, N_{pr}^{2/3} = f/2 \quad \ldots\ldots\ldots (2)$$

based on empirical reasoning. Although Colburn's equation applies best to flow in tubes, his "J factor" is now widely used to express the heat transfer performance of complex surfaces. Taylor[4] considered the similarity between the vorticity of fluid particles transferred (instead of the momentum) to the heat transfer process and obtained

$$N_{st} = f \quad \ldots\ldots\ldots\ldots\ldots (3)$$

which Bakhmeteff[5] also developed through an analogy in terms of kinetic energy transfer. von Karman[6] and others have also proposed similar though more elegant equations of the same general form.

The major weakness of all these analogies may be quickly noted. Since they depend on a comparison of heat transfer and momentum transfer (Reynolds, Colburn, von Karman) or heat transfer and eddy motion (Taylor, Bahkmeteff) they cannot serve in the general case of a surface in which both surface friction and form drag are sources of pressure drop.

THE f AND J RELATIONSHIP FOR LAMINAR FLOW

The relationships noted above are derived on the assumption of turbulent flow. Recent data on many surfaces[7] operating in both the laminar and turbulent region permit the establishment of a relationship between J and f for laminar flow. By plotting the heat transfer J versus f at various laminar Reynolds Numbers, it became obvious that the two quantities were related. Figure 1 shows a typical plot at a Reynolds Number of 600. Two curves actually seem to exist, the distinction being between those surfaces which present a staggered array of tubes to the flow and all others. Although this curve is drawn solely from the data of London and Kays, it should be remembered that a great many kinds of surfaces are represented. In the "staggered" class are bare tube-banks, spirally-finned tube-banks, and staggered pin fins. In the "non-staggered" class are plain, round tubes, grooved tubes, in line tube-banks, plain plate-and-fin surfaces, wavy and interrupted fin surfaces, and finned flattened-tubes. The three points labeled "partially staggered" refer to three finned flattened-tube surfaces in which each tube in the gas flow direction is only slightly offset from the one in front. As might be expected, these fall between the two other classes. The position of the two correlation lines seems to remain constant up to a Reynolds Number of about 800. At this point, the staggered class begins to lose its advantage, and the slope of both correlation lines begins to decrease. For the laminar region below a Reynolds number of 800

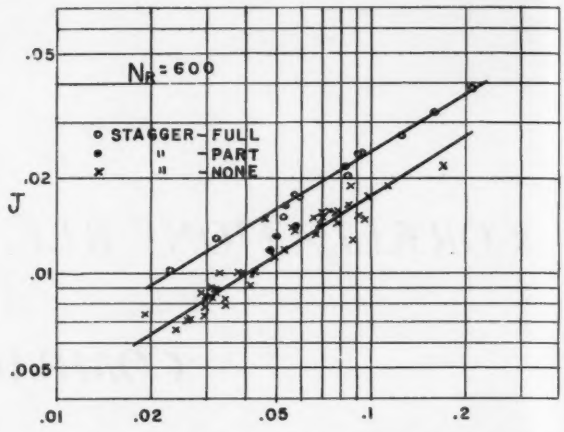


Figure 1. A plot of J versus f for the Reynolds Number of 600 shows the two distinct lines that result for the staggered and non-staggered surfaces. This plot will apply to any Reynolds Number less than 800.

$$J = .098\, f^{.6} \quad \ldots\ldots\ldots\ldots (4)$$

holds true for the staggered class and

$$J = .074\, f^{.63} \quad \ldots\ldots\ldots\ldots (5)$$

is the best line for the non-staggered class of surfaces.

Between a Reynolds Number of 800 and 4000, no single equation will relate f and J, although at any given Reynolds Number in this range, it is possible to correlate the data as well as at 600.

TURBULENT FLOW

Above a Reynolds Number of 4000, the f versus J correlation for all surfaces does not change, although it is a quite different function when compared with the laminar region. Figure 2, made at 10,000 is typical. This plot includes not only all the London and Kays data, but data of Washington and Marks,[8] and

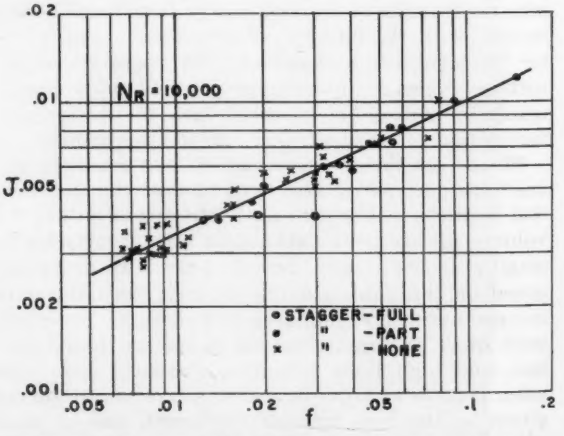


Figure 2. The correlation of J with f at a Reynolds Number of 10,000 is seen to be independent of stagger. This correlation applies to the Reynolds Number region above 4000.

Cope [9] as well. The correlation line can be represented by

$$J = .030\, f^{.47} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

and it is apparent that the distinction between staggered and non-staggered surfaces does not exist in the turbulent region.

One factor was noted that seemed to influence the position of a surface on the correlation line. Figure 3 shows 3 points plotted from Cope's data, each point being labeled with ratio of pyramid-shaped roughness height to tube diameter (¾ inch in all cases).

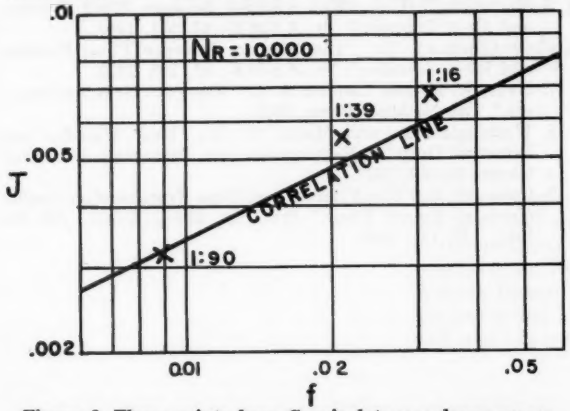


Figure 3. Three points from Cope's data are shown superposed on the correlation line from Figure 2. Each point is labeled with the ratio of round tube diameter (¾ inch for all three points) to pyramid-shaped roughness-height. As the roughness height approaches the diameter the point moves up along the line, suggesting that roughness is one of the factors influencing a surface's position on this plot.

From this plot it appears that roughness increase will move a surface out along the line. Obviously, roughness is not the only factor influencing a surface's position. If it were, all surfaces would give a single point in laminar flow, where roughness has theoretically little effect.

Although the points are somewhat scattered in Figure 2, seventy per cent of them fall within plus or minus ten per cent of the line in the J direction, and all but one (a low point) fall within plus or minus twenty per cent in the J direction. In other words, if we assume an f value, equation 6 will give the expected J value for any class of surface considered here. By adding twenty per cent to this median J value, we arrive at the most optimistic J value permissible on the basis of the data. While the area above this curve is "not allowed," the area beneath may contain points from heat transfer tests. In fact, any surface that fell far under the line would be a poor one, and not up to the standards set by most of the London and Kays surfaces.

DISCUSSION

The writer has used plots similar to those shown in Figures 1 and 2 as a rapid and effective check on test data coming from new types of heat transfer surfaces. If a point lies on the line, but further along the line than experience would suggest was reasonable, then the possibility of excessive roughness should be considered. For example, a brazed aluminum or steel unit with many fins may, as each model is tested, locate points scattered along the line. This suggests poor quality control in the braze application. Too much brazing compound will coat the fins and produce an appreciably roughened surface. If a surface falls well below the line, it is probably a poor design, and should be reworked. Surfaces that suffer fouling of their fluid passages during test tend to show a horizontal movement on the J versus f plane with time. As the gas passages become blocked, more flow is diverted through the remaining passages causing an increase in the actual heat transfer coefficient and only a small change in the apparent one. The pressure drop, however, will increase greatly and with it the apparent friction factor.

A surface that suffers deterioration of its fins, or fouling of its fins with a layer of high-thermal-resistance material will display a vertical movement downward on the J-f plane, since the apparent heat transfer coefficient will be decreasing, while the friction factor will be relatively unaffected. There is no physical reason known to the writers why a new surface should not lie above the line, but the test engineer should certainly view with suspicion any data that seems to give such a point. Figure 4 illustrates these various symptoms and gives the diagnosis for each.

The correlations given here have another very useful application in the preliminary design of thermal systems using new and compact heat exchangers. Consider, for example, the problem of fitting a regenerator in front of the burner cans on a small gas turbine unit. Taking a reasonable value for the ratio of gas side heat transfer area to exchanger volume, the designer can estimate the maximum frontal area

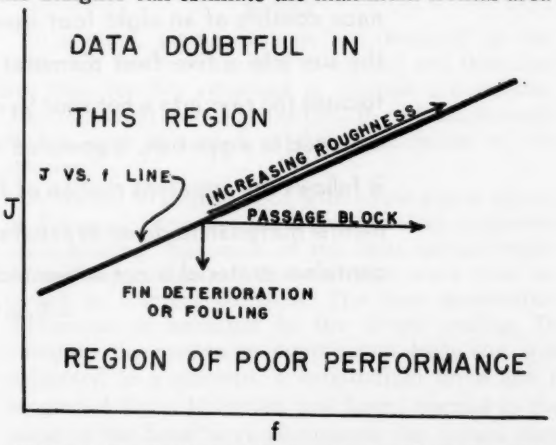


Figure 4. By plotting a point from test work on the established correlation line, something may be learned of the operation of the test piece. If its surface is roughened, either by fabrication or oxidation during test, it will move out along the line. Blocked passages and fouled fins give their characteristic indication as shown. On life tests on heat transfer equipment, the engineer should periodically rerun a given Reynolds Number and look for change of point position on the J-f plane.

and gas flow depth and then the gas side coefficient required to do the job. With this he can obtain J and enter a suitable correlation curve (Figures 1 or 2 if the Reynolds Number range is correct) to obtain the lowest possible f available. Using f, the pressure drop through the unit can be computed. If it is less than the maximum desired, then the application is a feasible one, but if the computed pressure drop is too large, the heat exchanger is probably an impossible design and more room must be provided. Such a calculation is quickly done and eliminates searching through fifty or a hundred surface performance curves in several references for a "miracle" surface that does not exist.

In short, the correlations presented here, though they have no theoretical basis, give a firm base on which to establish new experimental work or begin new application designs. An explanation as to why these correlations exist would, however, make them more valuable in the work yet to come.

REFERENCES

1. London, A. L. and Kays, W. M., "The Liquid-Coupled Indirect-Transfer Regenerator for Gas Turbine Plants," *ASME Preprint No. 50-A-89*, 1951.
2. Armour Research Foundation, "Study of Effects of Turbulence Promoters on Heat Transfer, Final Report," *NEPA-1559*, August 3, 1950.
3. Colburn, A. P., "A Method of Correlating Forced-Convection Heat Transfer Data and a Comparison with Fluid Friction," *Tr. A.I.Ch.E. 29*, 174, 1933.
4. Taylor, G. I., "The Transport of Vorticity and Heat through Fluids in Turbulent Motion," *Proc. Roy. Soc., A., 135*, 685, 1932.
5. Bakhmeteff, B. A., "The Analogy between Fluid Friction and Heat Transfer," *Tr. A.S.M.E., 62*, 551, 1940.
6. von Karman, Th., "The Analogy between Fluid Friction and Heat Transfer," *Tr. A.S.M.E., 61*, 705, 1939.
7. Kays, W. M. and London, A. L., "Compact Heat Exchangers," The National Press, 1955.
8. Washington, L., and Marks, W. M., "Heat Transfer and Pressure Drop in Rectangular Air Passages," *Ind. Eng. Chem., 29*, 337, 1937.
9. Cope, W. F., "The Friction and Heat Transmission Coefficients of Rough Pipes," *Pro. Inst. Mech. Engrs., 145*, 99, 1941; *146*, 141, 1941.

The National Bureau of Standards has placed in operation a solar furnace for high temperature research. The furnace can produce temperatures up to 3500° C to melt refractories in a contaminant-free environment. The furnace consists of an eight foot square flat mirror which directs the rays of the sun into a five foot diameter parabolic mirror. The parabolic mirror focuses the rays into a hot spot 1/4 inch in diameter. The flat mirror, suitably mounted in a gymbals, is powered in response to photo-electric cells so that it follows the apparent motion of the sun. It is possible to place the experimental material inside an evacuated glass container, positioned so that the container material is not subjected to the high focal-point temperature.

—from "Journal of the Franklin Institute," August 1957

JAMES H. POTTER

FULL SCALE STRESS EXPERIMENTS ON SOME COMMON PIPE BENDS

THE AUTHOR

was born in the City of New York and was educated in engineering at Columbia and at the Johns Hopkins University. In addition to five years in the chemical and shipbuilding fields, he has had seventeen years of experience in research and teaching at the University level. He has filled academic assignments at Johns Hopkins University, the University of Illinois, and the Stevens Institute of Technology. Since 1955 he has been Dean of Graduate Studies at the latter institution. He has been a member of the A.S.N.E. since 1939 and has contributed several other papers to the JOURNAL.

INTRODUCTION

As technology moves forward, piping systems become increasingly complex and expensive. It has been estimated that the piping costs in a modern central station account for nearly thirteen percent of the capital investment in equipment. In a present day oil refinery this figure would be more than doubled; correspondingly high piping costs would be found in many of the process industries.

The piping systems in all such high temperature installations must be designed for continuous performance and safe operation. Flexibility must be considered as it affects the stresses and deflections in the lines and in terms of the reactions imposed by the lines upon the vessels they connect.

Much thought and effort has been given to the design aspects of piping systems.[1] However, very little has been done either in field testing of lines or in experimental studies on full scale piping.* Model tests [1 2 3 4] have been used to check computed stresses, and a highly successful model technique has been established.[1]

The objective of the present investigation was to check computed pipe stresses against those measured on full scale test specimens. In order to effect fullest possible control of the variables involved, only simple bends in one plane were considered. Three 90 degree bends were prepared for three inch pipe, each with legs of equal length, to a centerline distance of eight feet. One bend was made with a standard three inch welding elbow. The second bend was formed from three inch pipe curved to a 20 inch radius. A single mitre bend completed the test group.

Stresses were measured with electric strain gauges on each end of the pipe near the flange, and on opposite sides of the pipe. This made possible a determination of maximum compressive and tensile stress at each end of the line. A second set of gauges was located one foot beyond the flange gauge station.

THEORY

In general, piping systems are designed on the basis that the lines are free to expand and that they are then forcibly returned to original orientations. The forces and moments required to restrain the ends of the lines are used in the computation of the stresses.*

A simple 90 degree bend with equal legs is shown in Figure 1. It is assumed that the line expanded upon heating, that each of the ends moved freely during expansion, and that the ends were then restored to original positions. The line shape after restoration is indicated by the dotted outline. To maintain the system in equilibrium each end was subjected to a moment, a longitudinal force and a tangential force. If torsion and forces normal to the plane of the bend were eliminated, the system may be described by simple equations in F_x, F_y, and the moment in the x-y plane.

As it is the purpose of this paper to compare measured and calculated stresses, no critical study of the derivation of the theoretical equations will be under-

* One outstanding exception was the work of R. L. Dennison on corrugated and creased bend piping at the U. S. Navy Engineering Experiment Station. See Journal A.S.N.E., vol. 47, No. 3, 1934, pp. 343-432.

* A complete treatment of the theory of pipe stress analysis is given in reference (1).

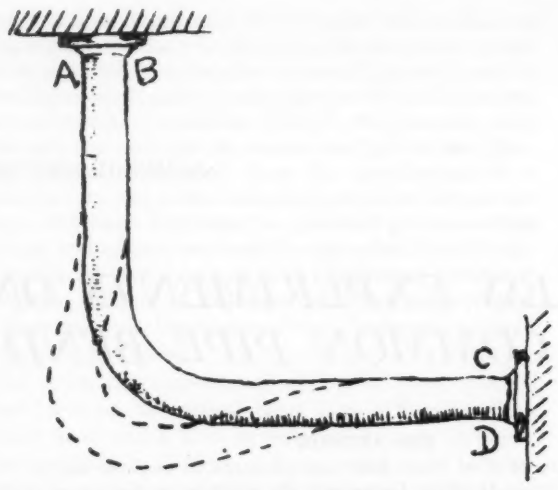


Figure 1. Simple bend with fixed ends. Dotted outline indicates displacement due to expansion.

taken. This has been done and is fully documented in reference (1).

A diagrammatic representation of one of the test bends is shown in Figure 2. The bend is maintained in equilibrium under a system of moments and forces with positive directions assumed as shown by the arrows. The origin of coordinates was taken at the West end.

If the flanges are prevented from rotating, the elastic equations describing the moment and forces at the origin are given as:

$$\begin{aligned} M_z\,(S) &+ F_x\,(S_b) &- F_y\,(S_a) &= 0 \\ M_z\,(S_b) &+ F_x\,(S_{bb}) &- F_y\,(S_{ab}) &= EI\Delta X \\ -M_z\,(S_a) &- F_x\,(S_{ab}) &+ F_y\,(S_{aa}) &= EI\Delta Y \end{aligned} \quad \ldots\ldots\ldots\ldots (1)$$

where:

E = modulus of elasticity
I = moment of inertia
ΔX = displacement to restore South flange in the x direction
ΔY = displacement to restore South flange in the y direction.

S, S_a, S_b, S_{aa}, S_{bb}, S_{ab} are "shape factors" depending upon the design of the line.

For a gauge station taken above the origin, the moment is modified by the product of the tangential force and the distance from the flange face to the gauge station:

$$M_s = M_z - F_x(y_s) \quad \ldots\ldots\ldots\ldots (2)$$

The bending stress is given by:

$\delta_{BS} = \dfrac{M_s}{Z}$ where Z is the section modulus.

The longitudinal stress is given by $\delta_{LS} = \dfrac{F_y}{A}$ where A is the cross sectional area of the pipe. The combined stresses are then:

$$\begin{aligned} \delta &= -\delta_{BS} - \delta_{LS} \quad \text{(compression)} \\ \delta &= +\delta_{BS} - \delta_{LS} \quad \text{(tension)} \end{aligned} \quad \ldots\ldots\ldots\ldots (3)$$

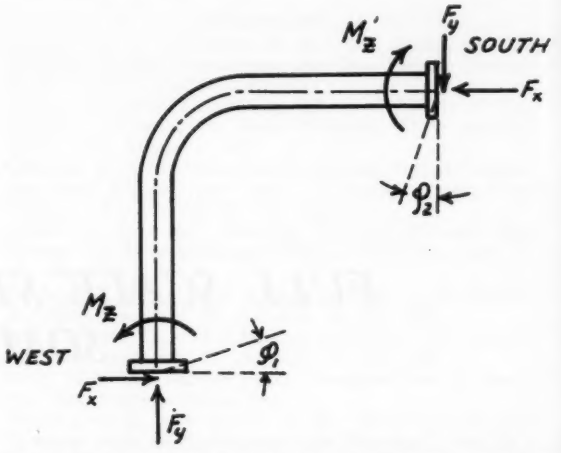


Figure 2. Representative pipe bend showing assumed directions of forces, moments and end rotations used in theoretical analysis. Origin was considered to be at West end.

For a gauge station taken just before the South flange, Fig. 2:

$$M_r = M_z - F_x(Y_r) + F_y(X_r) \quad \ldots\ldots\ldots\ldots (4)$$

where X_r and Y_r are the distances from the origin to the gauge station. Compressive and tensile stresses are found as before:

$$\delta_{Br} = \frac{M_r}{Z}; \quad \delta_{Lr} = \frac{F_x}{A};$$

$$\begin{aligned} \delta &= -\delta_{Br} - \delta_{Lr} \quad \text{(compression)} \\ \delta &= +\delta_{Br} - \delta_{Lr} \quad \text{(tension)} \end{aligned} \quad \ldots\ldots\ldots\ldots (5)$$

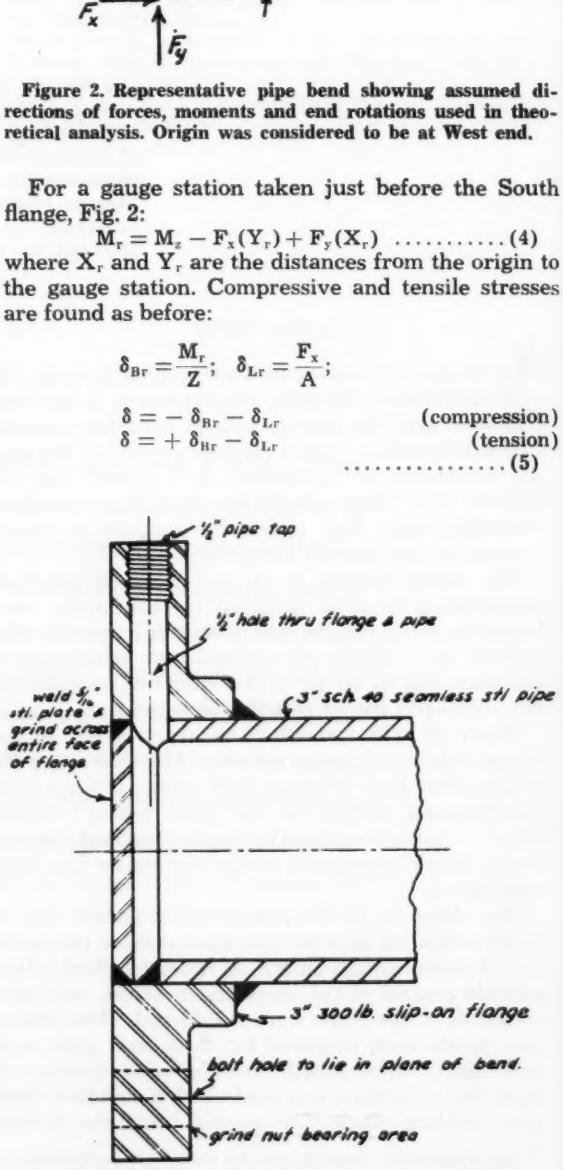

½" pipe tap
½" hole thru flange & pipe
3" sch. 40 seamless stl pipe
weld ⅛" stl. plate & grind across entire face of flange
3" 300 lb. slip-on flange
bolt hole to lie in plane of bend.
grind nut bearing area

Figure 3. Detail of flange used on test lines.

The force and moment determinations become much more complex if the flanges are assumed able to deflect slightly. Equation (1) then becomes:

$$\begin{aligned} M_z\,(S) &+ F_x\,(S_b) - F_y\,(S_a) = EI\,(\varphi_1 + \varphi_2) \\ M_z\,(S_b) &+ F_x\,(S_{bb}) - F_y\,(S_{ab}) = EI\,[-\Delta X + Y_r\,\varphi_2] \\ -M_z\,(S_b) &- F_x\,(S_{ab}) + F_y\,(S_{aa}) = EI\,[-\Delta Y - X_r\,\varphi_2] \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

In equation (6) the flange rotations are represented by φ_1, at the original and φ_2 at the far end, measured in radians. When the rotations tend to relieve the end moments, they are taken as negative in sign. The moments M_s and M_r are computed as before, and the stresses at the several gauge stations can be determined.

TEST SPECIMENS

The test bends were made from standard three inch schedul-40, seamless steel pipe. A three inch welding elbow was used in the "short radius" bend. A 20 inch radius was used in the "long radius" bend. A simple 45 degree weld was used in the single mitre bend.

The ends were welded to 300 lb. slip-on flanges. The flange detail is shown in Figure 3. The pipe was welded to the flange with external and internal fillet welds. A circular steel plate 5/16" thick was then welded into the bottom of the flange. Care was taken to locate two of the bolt holes of the flange in the plane of the pipe bend. The flange was ground off normal to the pipe axis after all welds were made.

Between two of the bolt holes a radial hole was drilled. The outer end was then tapped for ½ inch pipe. This provided a connection for the steam runs which followed the cold stress experiments.

TEST FACILITIES

In order to provide rigid anchors capable of sustaining large forces and moments, the lines were attached to the walls in the basement of the old power house at the University of Illinois. To simulate the end motions due to expansion, the pipe flanges were bolted to slider plates designed specifically for this duty. The test arrangement is shown diagrammatically in Figure 4. Slider plates B, B, are mounted at right angles. The test bend is hung in spring supports A, A, prior to bolting to the slider planes, and during test.

The slider plates were machined from mild steel stock 1¼ inches thick. The plates were 10¾ inches wide and 18 inches long. They were tapped for the cap screws which held the flanges to them. The slider tracks were made from 1 inch mild steel plate 20 inches wide and 26 inches long. A central block of steel on each track section was tapped for a 1 inch traversing bolt having 25 threads per inch. The bolts terminated in spherical heads which fitted into sockets at either end of the slider plate. A square nut was milled on the outer end of each traversing bolt.

The accurate location of the plates was of paramount importance to the success of this research, and great care was exercised. After selecting the area where the tests were to be run, the slider tracks were set in approximate positions and the slider plates were installed. Heavy jacks were placed under each assembly and the heights were adjusted. A transit was then set up and the center of the bolt ring on the slider plate was sighted. Each plate was then traversed for full travel. The jacks were adjusted until the punch mark "rode" the cross hair of the telescope. After this adjustment the anchor bolts were driven, fastening slider tracks to the wall. At this point the plates were located at the same height and were capable of traversing at this height. However, there was still the requirement that the plates be normal to each other.

A spectroscope with a Gauss eyepiece was set up as shown in Figure 5. A small mirror was fastened to each slider plate face. When the cross hairs in the telescope coincided with the image of the cross hairs reflected back from one mirror, the axis of the spectroscope was normal to that plate. The anchor bolts were adjusted until the Gauss eyepiece showed that the plate was normal. The vernier on the spectroscope table was then turned through 90 degrees and the second plate was adjusted. After the plates had been set normal to each other, a light grout was poured around each set of tracks.

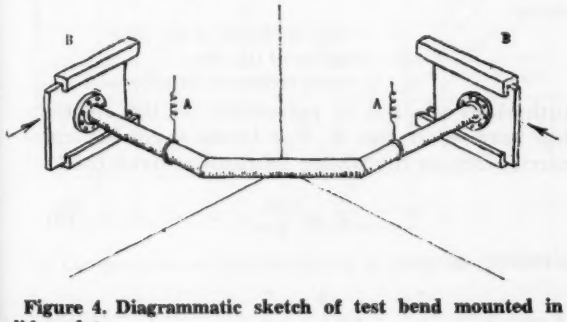


Figure 4. Diagrammatic sketch of test bend mounted in slider plates.

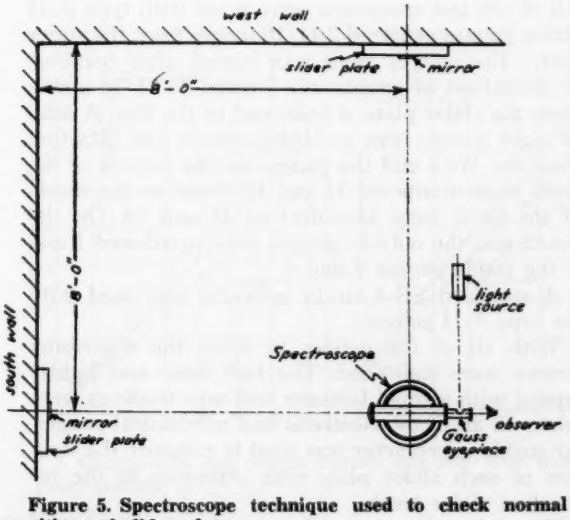


Figure 5. Spectroscope technique used to check normal positions of slider plates.

TEST METHOD

Reference to Figure 4 shows that coil springs A, A, were used to hang the pipe bend. Actually, two special assemblies were built, in each of which four small helical springs were attached to a turnbuckle. These assemblies were located so as to support the freely suspended test bend in the horizontal plane. The flanges were then bolted to the slider plates.

In Fig. 6 one of the slider plate assemblies is shown. The flange is bolted to the slider plate which in turn is held by the two large traversing screws. A steel block is mounted on the flange. This holds a steel bar which is used to measure the flange rotation. Two dial gauges with 0.0001-inch scale divisions act over a 31 inch gauge length to measure the angular rotation.

Baldwin Southwark electric resistance strain gauges were used. In Figure 6 a strain gauge is shown mounted between the fillet weld on the flange and the tape that holds the lead wires.

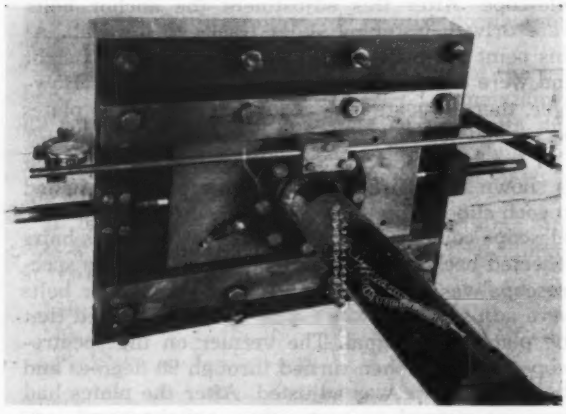


Figure 6. Slider plate detail showing traversing screws, strain gauges, and bar assembly for measuring flange rotation.

All of the test specimens were fitted with type A-11 strain gauges centered 2 11/16 inches from the slider plate. The gauges were wax coated after bonding. A second set of gauges was located 14 11/16 inches from the slider plate at each end of the line. A total of eight gauges was needed for each test. Starting from the West end the gauges on the outside of the bend were numbered 11 and 12; those on the inside of the bend were identified as 13 and 14. On the South end the outside gauges were numbered 1 and 2; the inside gauges 3 and 4.

A standard SR-4 strain indicator was used with the type A-11 gauges.

With all of the gauges in place the traversing screws were tightened. The test bend was lightly tapped with a small hammer and zero readings were taken on all of the electrical and mechanical gauges. An inside micrometer was used to measure the location of each slider plate with reference to the respective slider track.

The slider plates were then traversed toward each other in small increments until a total travel of 0.7 inches was reached. For each plate displacement the corresponding flange rotations were noted, and the electric strain gauges were read.

Following the double traverse runs, the West plate was fixed and only the South plate was traversed. All readings were taken as before.

After all of the cold stress runs were completed, each of the bends was tested with saturated steam. For these experiments, the West flange was fixed and the South flange unrestrained. The electric strain gauges were inoperative at the temperatures involved in the steam runs. Only plate displacements and rotations could be measured. The stresses were computed from these data.

RESULTS AND DISCUSSION

The graphs in Figures 7, 8, 9, 10, 11 and 12 show the stresses as a function of plate displacement for each of the cold runs. In each case the stresses for the "rigid" analysis are shown as curve "A." The general solution with allowance for the measured flange rotations is shown as curve "B." The electric strain gauge measurements are given in curve "C." The data for these graphs are presented in Tables I, II, III and IV.

At the conclusion of the experiment the flanges were cut off at approximately the strain gauge locations. At the same time tensile test specimens were cut from the pipes. These were tested according to A.S.T.M. specifications for pipe, and some test bars were also made from flattened annealed pipe sections. The modulus of elasticity was found to vary about 6% from an average value of 30,000,000 psi. The latter figure was used for all of the calculations. The selected value of the modulus does not affect the results for curves "A" and "B." However, the stresses reported along curve "C" are in fact the product of the modulus and the measured strains, so that accurate knowledge of the modulus is essential.

Perhaps the most important variable in the analysis was the flexibility factor, K, which is related to the bend characteristic h:

$$h = \frac{tR}{r_m^2} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

where

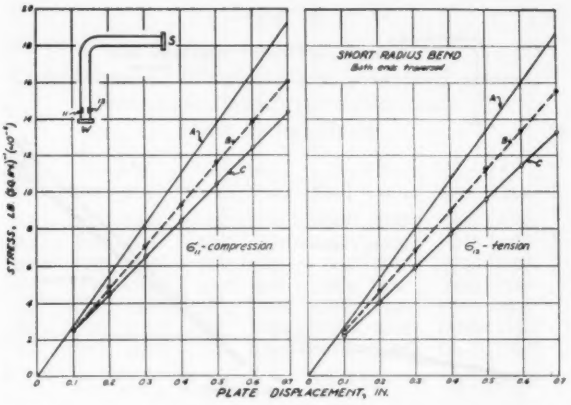
t = wall thickness of the pipe
R = radius of the bend
r_m = mean radius of the pipe wall

Authorities are not in agreement on the relationship between h and K. For bends involving commercial fittings the piping fabricators have used

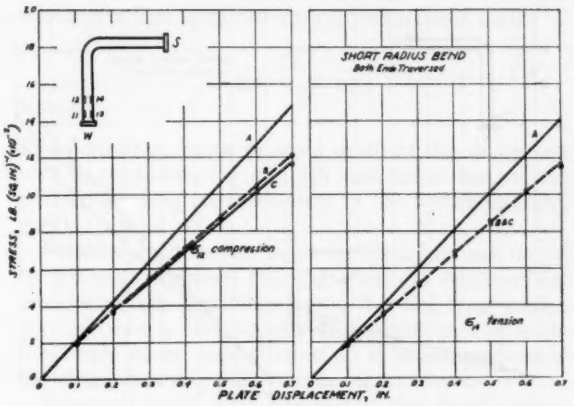
$$K = \frac{1.65}{h} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

Kármán[1] gives

$$K = \left[1 + \frac{9}{12h^2 + 1}\right] \quad \ldots\ldots\ldots\ldots\ldots (9)$$

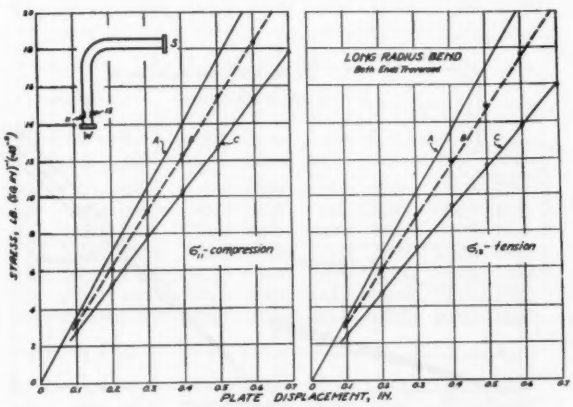


a. Compressive and tensile stresses at flange gauge station.

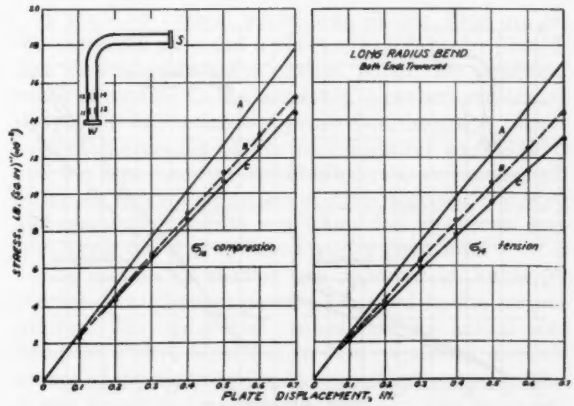


b. Compressive and tensile stresses one foot from flange gauge station.

Figure 7. Short Radius Bend.

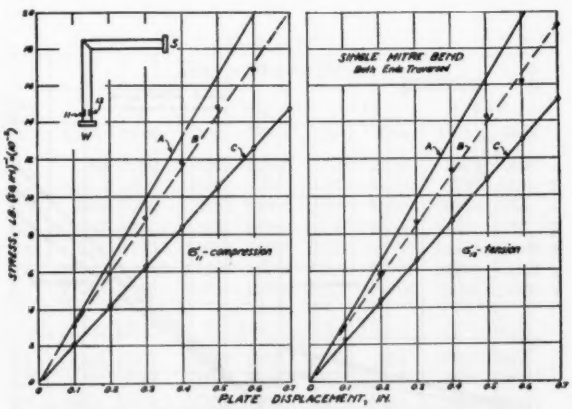


a. Compressive and tensile stresses at flange gauge station.

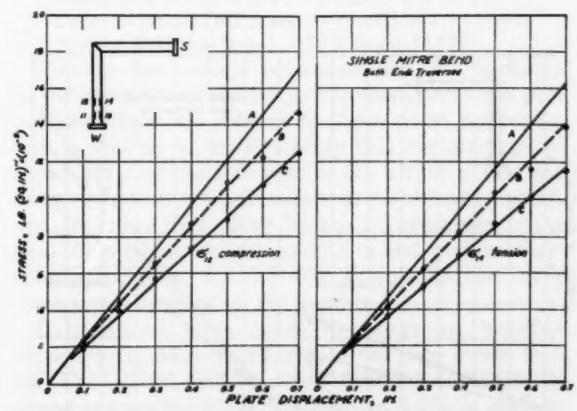


b. Compressive and tensile stresses one foot from flange gauge station.

Figure 8. Long Radius Bend.

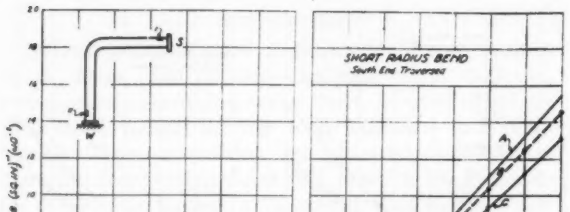


a. Compressive and tensile stresses at flange gauge station.

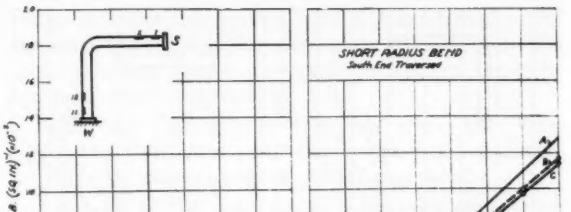


b. Compressive and tensile stresses one foot from flange gauge station.

Figure 9. Single Mitre Bend.

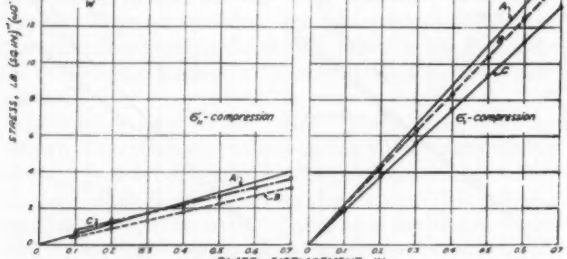


a. Compressive stresses at flange gauge stations.

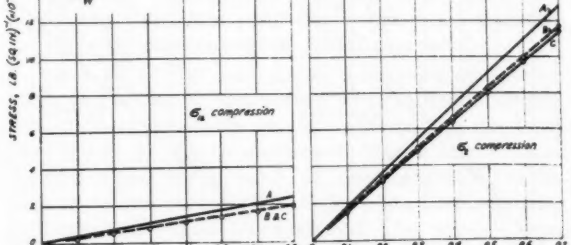


b. Compressive stresses one foot from flange gauge stations.

Figure 10. Short Radius Bend.

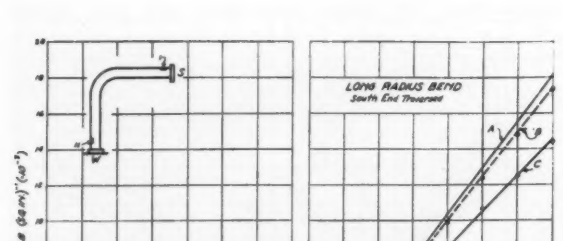


a. Compressive stresses at flange gauge stations.

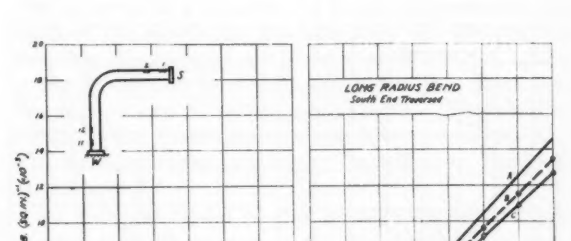


b. Compressive stresses one foot from flange gauge stations.

Figure 11. Long Radius Bend.



a. Compressive stresses at flange gauge stations.



b. Compressive stresses one foot from flange gauge stations.

Figure 12. Single Mitre Bend.

TABLE IA

Double Traverse Runs:
Comparison of calculated and measured stresses
Stresses in Pounds per square inch
Short Radius Bend

Plate Displ. in.	$(-)\delta_1$		$(+)\delta_3$		$(-)\delta_{11}$		$(+)\delta_{13}$	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
0.1	2575	2400	2497	2200	2499	2550	2421	2200
0.2	5143	4700	4991	4450	4871	4500	4715	4050
0.3	7708	7000	7486	6700	7089	6500	6855	5900
0.4	10254	9300	9960	8900	9291	8450	8981	7700
0.5	12860	11600	12492	11200	11652	10450	11264	9600
0.6	15432	13900	14992	13400	13905	12450	13439	11450
0.7	18003	16200	17491	15600	16121	14400	15579	13300
	$(-)\delta_2$		$(+)\delta_4$		$(-)\delta_{12}$		$(+)\delta_{14}$	
0.1	1966	2340	1888	1830	1901	1970	1823	1850
0.2	3933	4510	3781	3750	3695	3730	3539	3600
0.3	5897	6690	5675	5650	5359	5410	5125	5220
0.4	7847	8870	7553	7690	7009	7060	6699	6900
0.5	9844	11050	9476	9630	8792	8700	8404	8570
0.6	11815	13260	11375	11600	10482	10170	10016	10220
0.7	13785	13500	13273	13600	12147	11700	11605	11520

TABLE IB
Long Radius Bend

Plate Displ. in.	$(-)\delta_1$		$(+)\delta_3$		$(-)\delta_{11}$		$(+)\delta_{13}$	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
0.1	3318	2800	3206	2800	3135	2750	3019	2400
0.2	6646	5550	6426	5500	6105	5300	5877	4700
0.3	10017	8300	9685	8300	9263	7800	8919	7100
0.4	13390	11100	12946	11050	12411	10300	11951	9400
0.5	16727	13850	16175	13800	15468	12750	14894	11650
0.6	20021	16600	19363	16500	18359	15300	17673	13800
0.7	23265	19400	22501	19250	21143	17750	20343	15950
	$(-)\delta_2$		$(+)\delta_4$		$(-)\delta_{12}$		$(+)\delta_{14}$	
0.1	2424	2220	2312	2330	2265	2270	2149	2050
0.2	4871	4550	4651	4470	4400	4350	4172	3980
0.3	7342	6900	7010	6570	6686	6540	6342	5920
0.4	9820	9000	9376	8830	8967	8570	8507	7700
0.5	12269	11230	11717	11050	11173	10660	10599	9520
0.6	14688	13600	14030	13240	13242	12580	12556	11300
0.7	17051	15750	16287	15300	15204	14340	14404	13100

TABLE IC
Single Mitre Bend

Plate Displ. in.	$(-)\delta_1$		$(+)\delta_3$		$(-)\delta_{11}$		$(+)\delta_{13}$	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
0.1	3065	2300	2959	2150	3130	2100	3024	2300
0.2	5973	4700	5767	4350	5984	4180	5778	4400
0.3	8948	7050	8638	6600	8965	6300	8655	6550
0.4	12047	9400	11635	8800	11887	8400	11473	8700
0.5	15195	11800	14679	11100	14874	10500	14352	10900
0.6	18142	14150	17546	13300	16906	12600	16290	13050
0.7	21468	16500	20760	15500	20125	14700	19395	15200
	$(-)\delta_2$		$(+)\delta_4$		$(-)\delta_{12}$		$(+)\delta_{14}$	
0.1	2258	1800	2152	1800	2233	1830	2127	1998
0.2	4373	3740	4167	3800	4383	3940	4177	3620
0.3	6545	5570	6235	5460	6560	5660	6250	5240
0.4	8826	7430	8414	7430	8677	7370	8263	6960
0.5	11158	9370	10642	9220	10871	8870	10349	8720
0.6	13418	11420	12822	11370	12278	10770	11662	10090
0.7	15814	13230	15106	13120	14645	12450	13915	11580

which is a first approximation. Refinement yields

$$K = \left[1 + \frac{9}{12h^2 + 1 - j}\right] \quad \text{..... (10)}$$

where $j = f(h)$

The flexibility factor appears in all of the shape factors in equations (1) and (6) and hence has an important bearing on the values of the forces and moments.

For the short radius bend the K value was determined from equation (8). Equation (9) was used for computing the flexibility factor for the long radius bend. There is no theoretical analysis available on the single mitre joint. Hence no K values appear in the shape factors.

After all tests were completed the flanges were cut off in a plane through and normal to the electric strain gauges. The flanges were then mounted in a milling machine and the pipe edges squared. After polishing, these faces were measured to obtain the section characteristics.

A piece of carbon paper was placed, face up, on the sectioned pipe and a sheet of graph paper placed, face down, against the carbon paper. By applying gentle pressure to the assembly a carbon outline of the pipe cross section was printed on the graph paper.

Next the center of the configuration was located and the cross section was divided into segments each of which subtended an arc of 22½ degrees. The area and moment of inertia was found for each cross section using the appropriate transfer equations.

The section properties are reported in Table V. Published section properties are cited in the second column. The measured values for the actual sections lie within legal limits, but constitute another source of discrepancy for the computed stresses. Also it was found that none of the sections was truly circular and that wall thickness varied along the pipe circumference.

The section characteristics showed variations as follows:

Moment of Inertia from (−)0.033% to (+)4.53%
Cross sectional area from (−)2.64% to (+)3.68%
Section Modulus from (−)0% to (+)4.07%

Mention has already been made of a 6% variation in the modulus of elasticity. The analyses of the pipe configurations are subject to these gross discrepancies as well as to the flexibility (K) variations cited above. The errors inherent in the strain gauge and flange rotation measurements are extremely small, and are more than offset by the uncertainties in the flexibility factors, elastic modulus and section characteristics. Also, the last two quantities may vary from point to point in the system.

Calculations were made to determine whether shear effects were significant in the pipe bends tested. The shape factors were found to change by amounts varying from 0.0019% to 0.275%, and on this basis the shear contributions were considered to be negligibly small.

The slider plate clearances were measured in an

TABLE II

Double Traverse Runs:
Theoretical stresses computed without allowance for rotations of flanges.
Computed stresses, pounds per square inch, without allowance for rotations of flanges

Plate Displ. in.	Short Radius Bend				Long Radius Bend				Single Mitre Bend			
	(−) δ_1	(+) δ_3	(−) δ_{11}	(+) δ_{13}	(−) δ_1	(+) δ_3	(−) δ_{11}	(+) δ_{13}	(−) δ_1	(+) δ_3	(−) δ_{11}	(+) δ_{13}
0.1	2790	2600	2790	2600	3540	3430	3540	3430	3316	3205	3316	3205
0.2	5492	5328	5492	5328	7021	6780	7021	6780	6620	6400	6620	6400
0.3	8290	7980	8290	7980	10550	10130	10550	10130	9970	9635	9970	9635
0.4	11036	10704	11036	10704	14022	13540	14022	13540	13250	12800	13250	12800
0.5	13850	13360	13850	13360	17580	16930	17580	16930	16560	16000	16560	16000
0.6	16598	16102	16598	16102	21062	20340	21062	20340	20390	19710	20390	19710
0.7	19380	18750	19380	18750	24650	23730	24650	23730	23190	22410	23190	22410
	δ_2 (−)	δ_4 (+)	δ_{12} (−)	δ_{14} (+)	δ_2 (−)	δ_4 (+)	δ_{12} (−)	δ_{14} (+)	δ_2 (−)	δ_4 (+)	δ_{12} (−)	δ_{14} (+)
0.1	2100	1950	2100	1950	2550	2450	2550	2450	2520	2415	2520	2415
0.2	4210	4050	4210	4050	5150	4910	5150	4910	4930	4660	4930	4660
0.3	6300	6030	6300	6030	7740	7350	7740	7350	7360	7025	7360	7025
0.4	8470	8080	8470	8080	10270	9790	10270	9790	9850	9350	9850	9350
0.5	10560	10100	10560	10100	12840	12260	12840	12260	12250	11680	12250	11680
0.6	12730	12160	12730	12160	15420	14700	15420	14700	14680	14000	14680	14000
0.7	14760	14140	14760	14140	17980	17100	17980	17100	17130	16350	17130	16350

effort to estimate the effect of these clearances on the anchor rotations. The South plate clearance was 0.0145 inches and the West plate clearance was 0.0085 inches. These corresponded to equivalent angular plate movements of 0.00082 radians and 0.00048 radians respectively.

The linear nature of the "B" and "C" curves for each of the runs and the fact that they do not extrapolate through zero, suggests that the clearance is taken up at the time the specimen is attached to the slider plates and that no further effect is produced. This is further borne out by the fact that the angles needed to accommodate the slider clearances are of the order of magnitude of the maximum measured angular rotations.

The base gauge stations, 1, 3, 11, and 13 were selected in an effort to measure maximum stresses. However, the stiffening influence of the flange is bound to alter the elastic characteristics of the attached pipe according to the principle of St. Venant.[5]

For this reason the outer gauge stations 2, 4, 12, and 14 were added. Here the gauges were at a location at least 3.7 x D along the pipe, or well above the minimum distance recommended to eliminate the influence of the flange.

In Figures 7, 8, and 9 the results of the double traverse runs are shown. The most complete theoretical analysis available is for the short radius configuration. Consequently, best agreement between theory and measurement should be found. In Figure 7a the maximum tensile and compressive stresses are shown with the rigid analysis represented as "A," the modified computation at "B" and the measured stresses at "C." Remarkable agreement between computed and measured stresses is shown in Figure 7b at the outer gauge station.

The long radius bend is stiffer and the flexibility data less certain. The data in Fig. 8a show a wider spread than for the short radius bend. In Figure 8b the measured and computed stresses agree within the probable errors predicted above.

There is no theoretical analysis of the single mitre bend and it is interesting to note in Fig. 9a that there is closer agreement between the rigid and non-rigid calculations than between the latter and the measured values. Narrower variation is seen in Figure 9b.

In Figures 10, 11, and 12 the single traverse runs are shown. It will be recalled that the theory of pipe stress analysis is built around a system in which one end is fixed and one end displaced. It is interesting to note that the spread of the data is greatly reduced in each of the configurations.

The short radius bend shows closest agreement be-

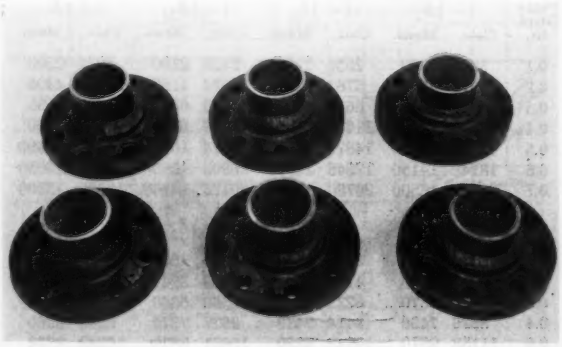


Figure 13. Test lines sectioned for measurement of actual dimensions.

TABLE IIIA

Single Traverse Runs:
Comparison of calculated and measured stresses
Short Radius Bend

Plate Displ. in.	$(-)\delta_1$		$(+)\delta_3$		$(-)\delta_{11}$		$(+)\delta_{13}$	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
0.1	2079	1880	2053	1760	459	720	407	420
0.2	4140	3750	4088	3550	947	1350	842	800
0.3	6232	5600	6156	5330	1401	1720	1244	1180
0.4	8315	7470	8213	7100	1900	2150	1690	1550
0.5	10380	9350	10256	8900	2366	2600	2104	1930
0.6	12487	11200	12333	10700	2823	3100	2509	2320
0.7	14577	13100	14399	12450	3333	3630	2893	2700
	$(-)\delta_2$		$(+)\delta_4$		$(-)\delta_{12}$		$(+)\delta_{14}$	
0.1	1676	1600	1647	1840	262	310	210	205
0.2	3328	3220	3276	3470	548	590	444	427
0.3	5012	4860	4936	5210	807	900	649	636
0.4	6687	6460	6585	6680	1104	1150	894	887
0.5	8351	8060	8223	8540	1373	1350	1111	1147
0.6	10045	9780	9891	10200	1633	1670	1319	1464
0.7	11725	11460	11547	11800	1944	1950	1504	1800

TABLE IIIB

Long Radius Bend

Plate Displ. in.	$(-)\delta_1$		$(+)\delta_3$		$(-)\delta_{11}$		$(+)\delta_{13}$	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
0.1	2513	2350	2467	2032	887	939	815	437
0.2	5005	4286	4915	4115	1755	1564	1611	934
0.3	7497	6420	7363	6009	2614	2451	2398	1522
0.4	9889	8650	9711	8150	3462	2944	3176	2100
0.5	12411	10642	12189	10214	4344	3797	3986	2580
0.6	14864	12488	14596	12356	5213	4457	4785	3111
0.7	17396	14420	17084	14300	6090	5100	5590	3810
	$(-)\delta_2$		$(+)\delta_4$		$(-)\delta_{12}$		$(+)\delta_{14}$	
0.1	1953	1980	1907	1840	536	390	464	280
0.2	3884	3830	3795	3820	1056	880	912	630
0.3	5807	5680	5673	5500	1569	1450	1353	1020
0.4	7679	7450	7501	7300	2079	1870	1793	1420
0.5	9631	9200	9409	9000	2612	2380	2254	1680
0.6	11554	10920	11286	10760	3137	2880	2709	2080
0.7	13526	12700	13214	12600	3666	3120	3166	2400

TABLE IIIC

Single Mitre Bend

Plate Displ. in.	$(-)\delta_1$		$(+)\delta_3$		$(-)\delta_{11}$		$(+)\delta_{13}$	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
0.1	2259	1830	2219	1780	797	480	733	405
0.2	4501	3680	4421	3540	1588	930	1460	830
0.3	6716	5530	6596	5310	2390	1400	2198	1260
0.4	8981	7360	8821	7080	3145	1860	2887	1680
0.5	11274	9200	11074	8850	3927	2320	3605	2120
0.6	13593	11030	13353	10640	4703	2800	4315	2540
0.7	15938	12880	15658	12400	5440	3270	4896	2980
	$(-)\delta_2$		$(+)\delta_4$		$(-)\delta_{12}$		$(+)\delta_{14}$	
0.1	1758	1630	1718	1560	485	290	421	260
0.2	3500	3300	3420	3030	964	570	836	490
0.3	5220	4500	5100	4400	1453	880	1261	730
0.4	7120	6030	6960	5970	1904	1170	1646	960
0.5	8770	7780	8570	7880	2371	1460	2049	1220
0.6	10580	9530	10340	9290	2834	1760	2446	1460
0.7	12410	11290	12130	10290	3267	2050	2813	1720

tween theory and measurement. The stresses at station 11, Figure 10a represent the only instance in which measured values exceeded those obtained from the rigid analysis. There is no explanation for this phenomenon. In Figure 10b the measured and computed stresses show remarkably close agreement.

The long radius bend Figure 11a and Figure 11b follows the general pattern. The uncertainty in the K values undoubtedly accounts for wider spread of the stress data.

The single mitre bend again shows closer agreement between the rigid and non-rigid analyses than between the measured and non-rigid stresses. This reflects the inadequacy of the theoretical analysis of the single mitre configuration.

After the cold stress runs each bend was tested with saturated steam, a radial pipe connection in the flange (Figure 6) was available at each end of the test specimen. The steam was admitted at one end and a small valve was left open at the other end until the line had been purged. The West slider plate was fixed and the South plate left free. Based upon the measured rotations, South end travel, and estimated thermal expansion the pipe stresses were computed for each gauge station. These are reported in Table VI.

CONCLUSIONS

This paper has dealt with only one small part of a very involved problem. On the basis of the bends tested it may be concluded that:

(1) The experiments performed in this research indicated that the present design technique, in which deflection of the flanges is not considered, is conservative.
(2) It would seem desirable to extend pipe research to further refine the flexibility factor data on curved bends.
(3) Research on pipe bends made from single or multiple mitre joints is necessary in order to establish the constants needed in the theoretical analysis of these bends.
(4) It is hoped that the extension of full-scale pipe bend research into three-dimensional area can be eventually undertaken.

ACKNOWLEDGEMENTS

Many people contributed generously of time and effort to this project. Professor N. A. Parker lent his encouragement and made available some Departmental research funds which were used to buy the test bends and slider plates. Professor M. K. Fahnestock followed the work closely and helped with suggestions and advice. Professor G. M. Almy of the Physics Department loaned the spectroscope and helped in some of the optical adjustments.

The work was originally undertaken as a laboratory investigation for graduate students. It is a pleasure to acknowledge the hard work done by Messrs. Hector Aiken, Don Barros, Mehmet Basci, Carl B[illegible]ment, T. K. Chow, Jesse Gamber, and Martin Osman.

Mr. Lale Andrews of the M. W. Kellogg Company

TABLE IV

Single Traverse Runs:
Theoretical stresses computed without allowance for rotations of flanges
Computed stresses, pounds per square inch, without allowance for rotation of flanges

Plate Displ. in.	Short Radius Bend				Long Radius Bend				Single Mitre Bend			
	(−) δ_1	(+) δ_3	(−) δ_{11}	(+) δ_{13}	(−) δ_1	(+) δ_3	(−) δ_{11}	(+) δ_{13}	(−) δ_1	(+) δ_3	(−) δ_{11}	(+) δ_{13}
0.1	2170	2100	550	480	2560	2470	940	850	2400	2360	790	730
0.2	4400	4340	1110	1000	5180	5080	1875	1730	4930	4850	1630	1500
0.3	6620	6530	1690	1510	7770	7600	2780	2590	7360	7250	2470	2250
0.4	8830	8720	2215	2005	10390	10200	3730	3460	9880	9720	3300	3020
0.5	11080	10940	2830	2540	13000	12700	4670	4310	12330	12130	4130	3750
0.6	13280	13120	3430	3060	15590	15310	5600	5180	14800	14560	4930	4510
0.7	15550	15400	3980	3590	18180	17800	6540	6040	17250	17000	5770	5280
	δ_2 (−)	δ_4 (+)	δ_{12} (−)	δ_{14} (+)	δ_2 (−)	δ_4 (+)	δ_{12} (−)	δ_{14} (+)	δ_2 (−)	δ_4 (+)	δ_{12} (−)	δ_{14} (+)
0.1	2040	1780	340	280	2050	1980	565	500	1950	1880	495	430
0.2	3810	3630	685	575	4175	4085	1145	1000	4020	3935	990	850
0.3	5580	5400	1025	870	6280	6150	1700	1495	5980	5850	1490	1280
0.4	7380	7215	1360	1140	8340	8160	2300	2000	8035	7870	2005	1730
0.5	9180	9080	1720	1430	10530	10260	2830	2490	10000	9770	2495	2140
0.6	10965	10795	2075	1740	12670	12390	3445	2995	12030	11780	2985	2575
0.7	12750	12680	2390	2020	14760	14370	3980	3480	14070	13750	3485	3000

TABLE V

Comparison of Measured and Tabular Values of Pipe Properties

Item	Tables	WEST Short Radius	WEST Long Radius	WEST Single Mitre	SOUTH Short Radius	SOUTH Long Radius	SOUTH Single Mitre
I, in.^{4}	3.02	3.027	3.157	3.098	3.137	3.028	3.019
A in.^{2}	2.23	2.234	2.310	2.291	2.312	2.252	2.171
γ in.	1.75	1.755	1.762	1.753	1.755	1.762	1.753
Z in.	1.72	1.725	1.790	1.765	1.785	1.720	1.720

TABLE VI

Steam Runs
Stresses Computed from Displacement and Rotation Data with saturated steam in the test bend.

	Short Radius Bend	Long Radius Bend	Single Mitre Bend
Psia.	166.7	169.5	161.7
T sat. °F	366.8	368.3	364.4
T °F	85.0	85.0	85.0
(−) 1	4490	5864	5209
(+) 3	4350	5676	5031
(−) 11	4639	5100	5070
(+) 13	4501	4900	4890

has been most helpful. He contributed many suggestions both before and after the experimental work.

REFERENCES

(1) "Design of Piping Systems," M. W. Kellogg Staff, Second Edition, 1956, John Wiley and Sons, Inc.
(2) "Model Test Analysis of Steam Piping," L. C. Andrews, *Combustion*, Vol. 20, No. 10, pp. 53-56.
(3) "Piping Flexibility Analysis by Model Test," L. C. Andrews, Transactions A.S.M.E., Vol. 74, No. 1, 1952, pp. 123-133.
(4) "Model Tests Solve High-Pressure Pipe Problems," J. C. Conrad, *Power*, Vol. 84, No. 10, 1940, pp. 58-61.
(5) "Theory of Elasticity," S. Timoshenko and J. N. Goodier, 2nd Edition, 1951, McGraw Hill, p. 33.

A method of programming piping design information in order to achieve automatic electronic computation of piping forces, moments, displacements, rotations and stresses has been developed by Dr. Leslie G. Peck. Any specific problem can be programmed with very little preparatory hand calculation. In addition to large savings in man-hours, the automatic computation process permits rapid and economical evaluation of the effects of changing design parameters in order to arrive at an optimum design.

—from "Journal of the Franklin Institute," May 1957

JET VERSUS TURBO-PROP

ACKNOWLEDGMENT

This reprint, originally published in the 22 February 1957 edition of "Engineering," is an abridged version of a lecture delivered before the Institute of Transport, by Marshal of the Royal Air Force Lord Douglas of Kirtleside, Chairman of British European Airways.

AIR transport today is embroiled in perhaps the most controversial issue of the whole 37 years of its existence—the future roles of pure jet and turbo-prop engines in the propulsion of transport aircraft. The British tax-payer has invested large sums in sponsoring these new engines, and several of the aircraft in which they are installed. It is therefore essential, if he is to get maximum return on his money, that the spheres of optimum application of the two types of gas turbine should be established and then energetically exploited.

Jet transport enthusiasts claim that this type of aircraft can offer continuing reductions in operating cost and, at the same time, make possible higher operating speeds. They claim, furthermore, that the speeds will be so much higher that other types of aircraft will be put out of business.

The case for the turbo-prop rests primarily on the claim that it makes possible substantially lower operating costs than can be achieved with the pure jet. The propeller turbine transport is seen as the only choice for the carriage of the great majority of future air traffic—which will insist on the lowest possible fare. The first-class market, which is prepared to pay for the quickest possible journey, will be only a fraction of the low-fare business.

In addition, the turbo-prop is claimed to be less exacting in its operating requirements. For example, it requires shorter runways, a wider range of cruising heights is possible, there is much less external noise, landings in poor visibility or on icy runways are likely to be easier and it suffers less penalty from heavy fuel reserves to provide for diversions from the intended terminal in bad weather.

It is, however, on an assessment of the likely effect of speed and cost on their operations that most airlines are deciding their future aircraft policy. In reaching their decisions airlines have to take account of two practical aspects of the problem:—*(a)* The higher cruising speeds of the jets may give important advantages in faster jounrneys only over the longer distances. Thus, a jet which is even 150 m.p.h. faster than a turbo-prop will be able to offer a journey only 20 minutes shorter on a stage of 500 miles —such as London-Zürich. A time-saving of this order may not be worth having if there are significant economic and operating objections to the faster vehicle. On the other hand, at the same fare, even 20 minutes could be competitively important. There would be little merit in having a lower-cost slower vehicle if it lost more of its traffic to a competing jet and failed to achieve an economic load factor. *(b)* A slower aircraft with a lower operating cost may be attractive to operators only if they are able to pass on their lower costs to their customers in the form of reduced fares. These, in turn, would attract the traffic in spite of the lower speed. However, on international routes, lower fares are dependent on agreement between airlines at the traffic conferences of the International Air Transport Association (IATA). If the traffic conferences did not agree on a fare differential between jets and turbo-props, the turbo-prop operator might easily be worse off with the lower cost but—at the same fare—less competitive vehicles.

COMPARATIVE PERFORMANCE

At the beginning of the 1960's the American "big jets," the Boeing 707 and the Douglas DC-8, are likely to offer cruising speeds close to 550 m.p.h. At the same time, the turbo-prop airliners, the later Vickers Viscounts and the first Lockheed Electras and Vickers Vanguards will be achieving speeds of 400 m.p.h. or more. As progress is made into the 1960's, the speeds of the jets will probably rise towards 575 m.p.h. while that of the turbo-props

should approach 460 m.p.h. The practical effect of these speed differentials is brought out in Table I. It shows clearly the small savings in block time (between airports) and therefore in journey (city-center to city-center) on the shorter journeys by using a 575 m.p.h. jet instead of a 460 m.p.h. turbo-prop. The time savings compared with the 375 m.p.h. turbo-prop are, of course, greater but they remain relatively modest over the shorter distances.

The indications are that, in hot weather, the American "big jets" will require runways about 12,000 ft. long for operations on long-stage routes such as the North Atlantic. Over shorter distances these aircraft will require about 10,000 ft. as will medium-haul jets in the class of the Convair CV-880. These runway lengths will have to be associated with pavement strengths adequate for aircraft with loaded weights of the order of 150 tons.

The increasingly large open spaces required by a modern airport are dictating sites further and further away from the centers of the cities they serve. Thus, in Sweden, Stockholm's old airport at Bromma, 5 miles from the city center, will have to be replaced by a new airport at Ska-Edeby, 14 miles from the city. This means that a 575 m.p.h. jet using the new airport will offer a slower city-center to city-center journey to its passengers than a 460 m.p.h. turbo-prop using Bromma on all stages of less than about 750 miles—say, as far as Frankfurt

Turbo-prop transports will be able to operate from significantly smaller airports than the equivalent jets. Thus, the long-range Bristol Britannia 310, intended for non-stop London-New York operation, will require a runway of about 7,500 ft. at full load. The medium-haul Britannia 100, Vickers Vanguard and Lockheed Electra have take-off distances of the order of 6,500 ft. Moreover, their lower gross weights to carry a given payload over similar distances mean that airport pavement strengths can be less, and airport construction is therefore cheaper.

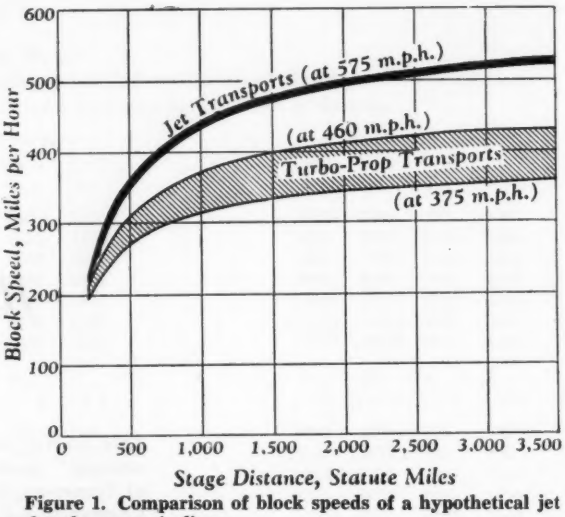


Figure 1. Comparison of block speeds of a hypothetical jet and turbo-prop air-liners.

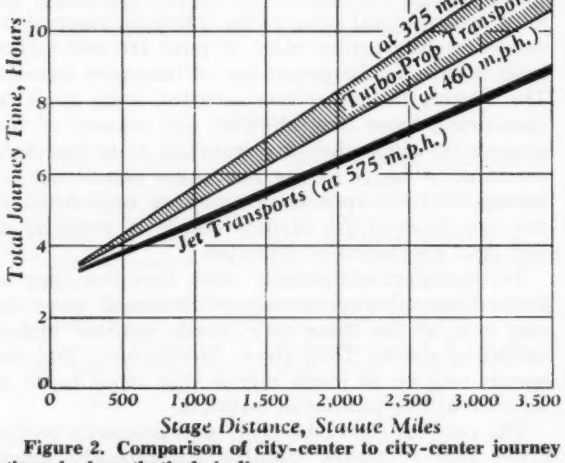


Figure 2. Comparison of city-center to city-center journey times by hypothetical air-liners.

COMPARATIVE OPERATING COSTS

British European Airways have made a study of hypothetical 575 m.p.h. jet transports with short, medium and long-range capabilities. These aircraft have been designed to carry a capacity payload of 25,000 lb. over stage lengths of 1,000 and 2,500 and 3,500 statute miles. The jet "paper airplanes" have been compared with two similar "families" of turbo-props with the same range characteristics and capable of carrying the same payload in an identical fuselage. One turbo-prop "family" cruises at 375

TABLE I—*Jet and Turbo-prop Comparative Speeds*

Stage length, statute miles	Typical stage	Block time (airport-to-airport)				
		575 m.p.h. pure jet	375 m.p.h. turbo-prop	460 m.p.h. turbo-prop	Time saving by jet competing with	
					375 m.p.h. turbo-prop	460 m.p.h. turbo-prop
		Hrs. Mins.	Hrs. Mins.	Hrs. Mins.	Hrs. Mins.	Hrs. Mins.
200	London-Paris	0 50	1 0	0 54	0 10	0 4
500	London-Zürich	1 23	1 48	1 36	0 25	0 13
700	New York-Chicago	1 42	2 23	2 03	0 41	0 21
900	London-Rome	2 03	2 55	2 30	0 52	0 27
1,100	London-Gibraltar	2 24	3 25	2 58	1 01	0 34
1,600	London-Moscow	3 17	4 47	4 01	1 30	0 44
2,500	New York-Los Angeles	4 50	7 05	5 54	2 15	1 04
3,500	London-New York	6 37	9 43	7 54	3 06	1 17

TABLE II—*Leading Characteristics of 100-Passenger Design Studies*

Aircraft type	575 m.p.h. jet			460 m.p.h. turbo-prop			375 m.p.h. turbo-prop		
	Short haul	Medium haul	Long haul	Short haul	Medium haul	Long haul	Short haul	Medium haul	Long haul
Design stage (st. miles).....	1,000	2,500	3,500	1,000	2,500	3,500	1,000	2,500	3,500
Max. take-off weight (lb.)....	135,000	180,000	225,000	115,000	140,000	165,000	105,000	125,000	145,000
Engines (4 × lb. thrust or s.h.p.)	8,500 lb.	10,000 lb.	11,500 lb.	5,000 s.h.p.	5,400 s.h.p.	5,800 s.h.p.	3,000 s.h.p.	3,250 s.h.p.	3,500 s.h.p.
Prime cost	£1,040,000	£1,190,000	£1,350,000	£930,000	£1,010,000	£1,080,000	£800,000	£840,000	£890,000
Take-off field length (ft.)	6,000	8,100	10,000	4,600	6,200	8,000	6,000	8,000	10,000
Landing field length (ft.).....	6,000	6,000	6,000	7,000	7,000	7,000	6,000	6,000	6,000

m.p.h., the other at 460 m.p.h. Fig. 1 compares their block speeds over different stage distances and Fig. 2 illustrates the resulting journey times between city centers. Table 2 gives the leading characteristics of the resulting design studies.

"Formula aircraft cost" (that is to say, calculated theoretical direct operating cost) estimates have been prepared for the nine hypothetical aircraft studied. The results of this comparison are illustrated in Figs. 3 and 4, from which it may be seen that the 575 m.p.h. jet has formula operating costs between 3 and 9 per cent higher than the 460 m.p.h. turbo-prop when operated over stage lengths of about the design range. However, as the stage length diverges from the design figure, an increasing economic advantage for the turbo-prop is apparent. This reaches something like 5 per cent for the short-haul aircraft and 10 to 15 per cent for the medium and long-haul designs. The slower 375 m.p.h. turbo-prop has significantly better economic characteristics than the 460 m.p.h. airplane. At its design range, the jet has a cost between 10 and 14 per cent higher. Away from the design point, this difference increases to 16 per cent for the short-haul aircraft and 20 to 30 per cent for the longer-haul types.

In Fig. 5 are shown estimated formula aircraft costs for the Vickers V.840 Viscount, the Sud-Est

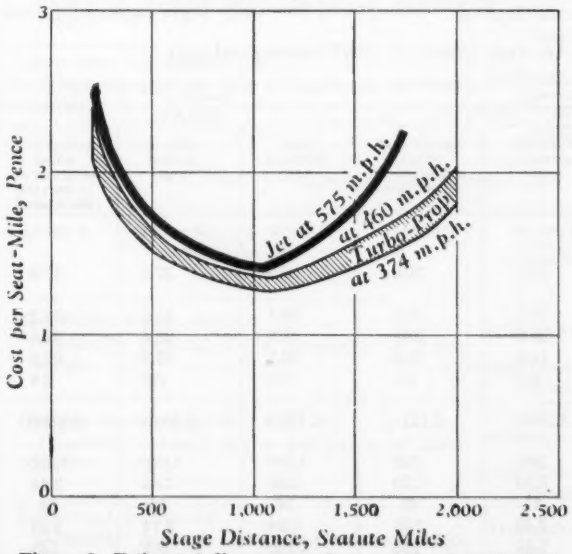


Figure 3. Estimated direct operating costs for hypothetical short-haul air-liners.

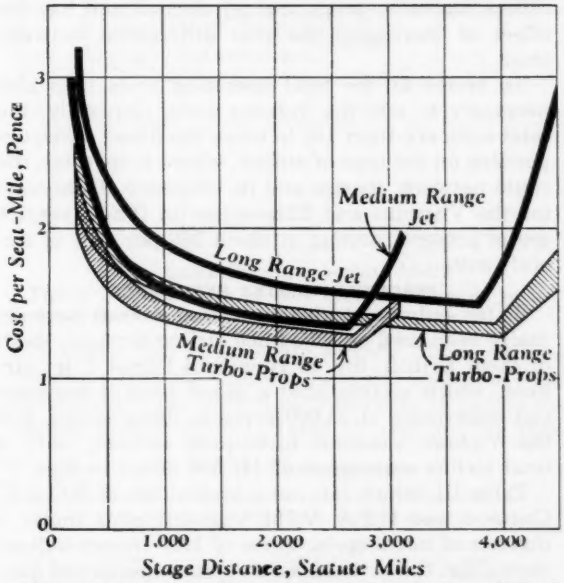


Figure 4. Estimated direct operating costs for hypothetical medium and long-haul air-liners.

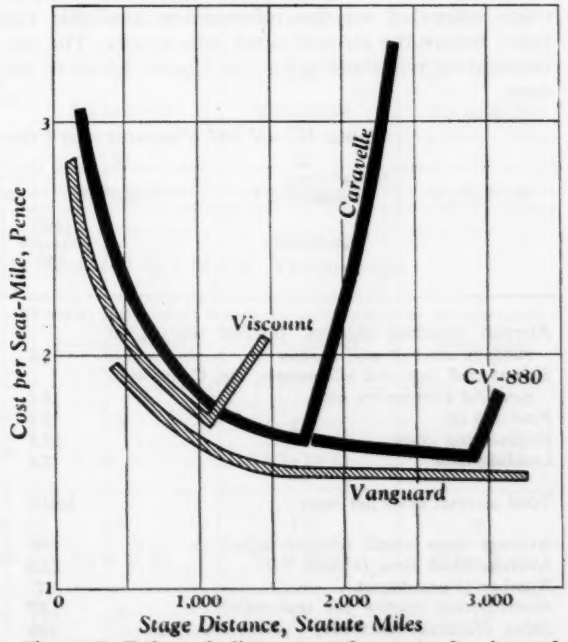


Figure 5. Estimated direct operating costs for jet and turbo-prop air-liners on order.

Caravelle, the Vickers V.951 Vanguard and the Convair CV-880. These aircraft are all on order by various airlines and should be in competing service during the next three to four years.

The above comparisons have all been based on formula aircraft costs determined by the B.E.A. method. Experience shows, however, that cost estimates of this kind, particularly when they are made some years before an airplane enters service, are likely to be optimistic. The adjustment required also differs for turbo-props and jet aircraft and has the effect of increasing the cost differential between them.

To arrive at the total operating costs it is also necessary to add the indirect costs. Generally, the total costs are from 1½ to twice the direct costs, depending on the type of airline, where it operates, the route network, its size and its efficiency. Total costs for the Viscount and Elizabethan in B.E.A. service are at present running at about 160 per cent of aircraft costs.

PRACTICAL TURBINE EXPERIENCE

So far, only two turbine-powered aircraft have actually been used on scheduled airline services—both of them British, the de Havilland Comet 1 jet airliner, which accumulated a grand total of commercial experience of 24,000 revenue flying hours, and the Vickers Viscount turbo-prop airliner, with a total airline experience of 442,000 hours to date.

Table III, which sets out a breakdown of B.O.A.C. Comet 1 and B.E.A. V.701 Viscount costs under a number of headings in terms of 1957 money values, shows that the actual aircraft costs experienced during the first year of airline service with the Viscount was 32 per cent higher than the formula aircraft costs estimated on the information available two years before the aircraft went into service. The corresponding relationship for the Comet 1 was 61 per cent.

Experience since the Viscount went into service suggests that the average actual aircraft costs for the Viscount at the mid-point in its life will be reduced to a figure 21 per cent higher than the formula aircraft costs. It is estimated that, for Comet 1, had it continued in service, the average actual aircraft costs at the mid-point in the Comet 1's life would have been reduced to a level equivalent to about 35 per cent above the formula aircraft costs estimated on the information available two years before the aircraft went into service.

There was, therefore, a differential between the relationship of actual to formula aircraft costs for the Viscount and Comet 1 of about 12 per cent. The Comet 1, in its day, represented a far greater technical step into the unknown than the Viscount or, indeed, than will be required of the jets of the future. For this reason, one would expect the ratio of actual to formula costs for the Comet 1 to be higher than can be anticipated for future jet aircraft. However, even in the future, there is likely to be some differential between the actual/formula cost relationships of jets and turbo-props. This is primarily because of the jet's greater operational inflexibility and because of their more "sophisticated" design which tends to exaggerate the economic effect of engineering changes. A reasonable assumption in extrapolating Comet 1 experience into the future might be to assume a reduction of one-third on the 12 per cent differential in the relationships of actual to formula aircraft costs for the Viscount and Comet 1. An arbitrary reduction of the differential to 8 per cent has therefore been assumed in the cost estimations for future aircraft types made later in this paper.

Some statistics of Viscount and Comet 1 operations are worth considering before concluding this brief examination of practical turbine transport experience. Fig. 6 brings out the very high passenger load

TABLE III—*V.701 Viscount and Comet 1 Aircraft Costs (in 1957 money values)*

Aircraft Type	V.701 Viscount			Comet 1		
Operator	B.E.A.			B.O.A.C.		
Type of cost	1950* formula cost	1953-54 actual cost	Actual cost when established in service	1949* formula cost	1952-53 actual cost	Actual cost when established in service (Estimated)
	£ per hr.	£ per hr.	£ per hr.	£ per hr.	£ per hr.	£ per hr.
Aircraft standing charges. Interest on capital sunk in aircraft and spares	17.6	20.5	20.9	29.9	37.0	37.0
Flying staff pay and allowances, etc. Cabin staff pay and allowances, etc.	16.7	16.1	15.2	20.1	37.3	26.2
Fuel and oil	19.4	23.8	23.8	70.0	92.6	92.6
Engineering costs	27.3	41.6	37.4	36.3	93.3	62.5
Landing fees	3.8	4.1	4.1	5.5	2.6	2.6
Total aircraft costs per hour	£84.8	£106.1	£101.4	£161.8	£262.8	£220.9
Average stage length (statute miles)	506	506	506	1,050	1,050	1,050
Average block time (hours)	2.19	2.30	2.20	2.86	2.84	2.84
Number of passengers	47	47	47	36	36	36
Aircraft cost (pence per seat-mile)	1.87	2.46	2.25	2.94	4.74	3.98
Index (formula cost=100)	100	1.32	121	100	161	135

* These formula costs are not the same as the costs which were actually estimated by B.O.A.C. in 1949 and B.E.A. in 1950. The costs forecast at those dates for the Comet and Viscount were based on earlier methods of estimation.

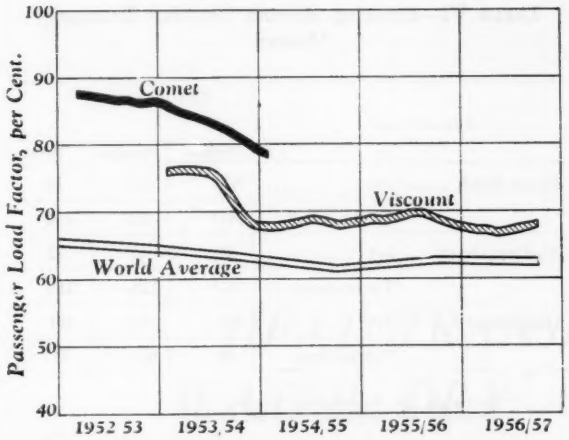


Figure 6. Passenger load factors achieved by the Comet 1 and Viscount air-liners.

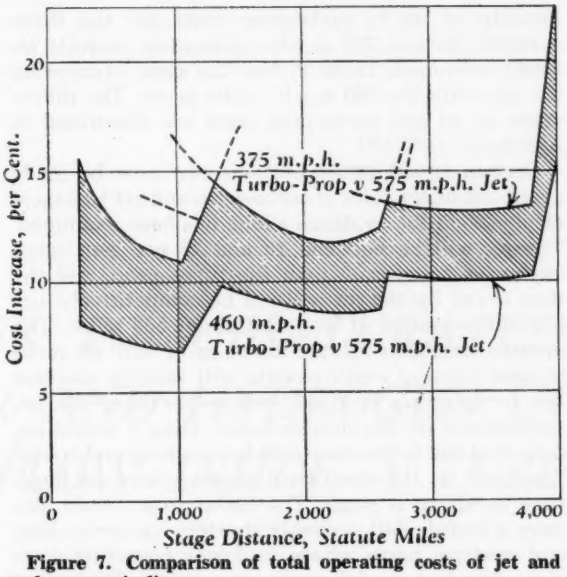


Figure 7. Comparison of total operating costs of jet and turbo-prop air-liners.

factors achieved by B.O.A.C. with the Comet 1 which helped to make these operations profitable in spite of the aircraft's relatively high cost characteristics. They also provide some confirmation—if it were needed—of the claims of the jet protagonists of the competitive importance of speed.

COST CONCLUSIONS

Assuming the 8 per cent differential in the actual-to-formula cost relationship already discussed, and assuming that the indirect costs are such that total costs are 160 per cent of aircraft costs (which is the present B.E.A. figure), Table IV sets out the rela-

TABLE IV—*Comparative Costs—575 M.P.H. Jets and 375 M.P.H. Turbo-props*

Range category	Point of comparison	Jet costs higher than turbo-prop costs (cost per seat-mile)		
		Formula aircraft costs, per cent	Actual aircraft costs, per cent	Actual total costs, per cent
Short-haul transports ..... (Capacity payload for a maximum of 1,000 miles)	At design range	10	18	11
	Away from design range	Up to 16–24	Up to 24–32	Up to 15–20
Medium-haul transports ..... (Capacity payload for a maximum of 2,500 miles)	At design range	12	20	12
	Away from design range	Up to 28–30	Up to 36–38	Up to 22–24
Long-haul transports ..... (Capacity payload for a maximum of 3,500 miles)	At design range	14	22	14
	Away from design range	Up to 28–32	Up to 36–40	Up to 22–25

TABLE V—*Comparative Costs—575 M.P.H. Jets and 460 M.P.H. Turbo-props*

Range category	Point of comparison	Jet costs higher than turbo-prop costs (cost per seat-mile)		
		Formula aircraft costs, per cent	Actual aircraft costs, per cent	Actual total costs, per cent
Short-daul transports ..... (Capacity payload for a maximum of 1,000 miles)	At design range	3	11	7
	Away from design range	Up to 5–12	Up to 13–20	Up to 8–12
Medium-haul transports ..... (Capacity payload for a maximum of 2,500 miles)	At design range	6	14	9
	Away from design range	Up to 12–24	Up to 20–32	Up to 12–20
Long-haul transports ..... (Capacity payload for a maximum of 3,500 miles)	At design range	8	16	10
	Away from design range	Up to 16–18	Up to 24–26	Up to 15–16

tionship of jet to turbo-prop costs for the three matched jet and 375 m.p.h. turbo-prop projects already examined. Table V does the same, comparing the jets with the 460 m.p.h. turbo-props. The differences in jet and turbo-prop costs are illustrated in Fig. 7.

Certain broad generalizations can now be made about the likely roles of turbo-prop and jet transport airplanes on the evidence which has been examined. The jet will be between 10 and 15 per cent more expensive to operate than the turbo-prop, and the time saved by the jet will not be competitively significant on stages of less than about 500 miles. The greater flexibility of the turbo-prop and its more modest runway requirements will tend to increase the turbo-prop's economic advantage over the jet, particularly on the shorter hauls. Thus it would appear that the turbo-prop will have a long and useful "innings" on the short-haul routes where its block time handicap is small. The turbo-prop should also have a useful—but probably shorter—career on long and medium hauls where its lower operating costs may give it a useful application in the lower-fare mass-travel market, particularly if a fare differential is accepted by the I.A.T.A. traffic conferences. The longer-range turbo-prop's future may, however, largely depend on whether the type succeeds in establishing itself in service before the "big jets" appear on the scene in large numbers. The recent entry into airline service of the Bristol Britannia is therefore important.

Past experience suggests that although roughly two-thirds of the world's passenger miles will be generated on the shorter hauls, about half this traffic will be carried in medium and long-range aircraft operated on short sectors. Because of this, it is reasonable to assume that the passenger miles provided by short, medium and long-range jet and turbo-prop aircraft are divided between them as follows:—

TABLE VI—*Existing Airline Turbine Transport Orders*

Aircraft type		Existing orders		
		British	Foreign	Total
Short-haul	Jet	Nil	12	12
	Turbo-prop ...	361*	53	414
Medium-haul ...	Jet	33	40	73
	Turbo-prop ...	57†	128	185
Long-haul	Jet	Nil	251	251
	Turbo-prop ...	38	Nil	38

* Including 174 Viscounts delivered.
† Including six Britannia 100 delivered.

short-haul aircraft, one-third by jets, two-thirds by turbo-props; medium-haul aircraft, one-half by jets, one-half by turbo-props; and long-haul aircraft, two-thirds by jets, one-third by turbo-props.

The numbers of new transport aircraft required by the airlines between 1957 and 1970 which result from the above assumptions are as follows: short-haul jets, 800; short-haul turbo-props, 2,500; medium-haul jets, 700; medium-haul turbo-props, 800; long-haul jets, 600; long-haul turbo-jets, 500.

An investment of perhaps £3,500 million will be required from the airlines to purchase the jet equipment and a further £3,000 million will be needed for turbo-props. These orders will, however, include those already placed (listed in Table VI) which are worth some £700 million on jets and £300 million on turbo-props.

The great controversy has yet to be resolved. However, the signs are that, before they pass into history, both jet and turbo-prop are destined to play essential parts in world transport.

A 35,000 foot long track for supersonic sled testing is under construction at Holloman, New Mexico. It is expected to provide test facilities for biophysical investigations of flight environments, for research on flutter and vibration characteristics of full scale aircraft and missile components and structures, and for acceleration proof testing of missile components. Such investigations can be conducted at very high speeds under test conditions generally superior to those obtained in free flight tests. Actual speeds attainable will not be known until further research is completed, but speeds up to Mach 5 are being investigated.

—from "Jet Propulsion," September 1957

IRVING GRANET

HEAT TRANSFER TO SUBSATURATED WATER, DRY AIR AND HYDROGEN IN TURBULENT FLOW INSIDE A TUBE

THE AUTHOR

Born July 2, 1924. Attended Brooklyn Technical High School and received the degree of Bachelor of Mechanical Engineering from the Cooper Union in 1944. Employed in 1944–45 on Navy Torpedo project as project engineer on stress and vibration studies. Subsequently served two years with Air Corps overseas as Flight Engineer. In June 1948 received the degree of Master of Mechanical Engineering from the Brooklyn Polytechnic Institute and in 1949 received Professional Engineering License in New York. Since 1947, employed by Foster Wheeler Corporation as Project Engineer, Research Department; then Director of Staff Engineering, Nuclear Energy Department. In 1955–56 attended the Oak Ridge School of Reactor Technology at Oak Ridge, Tennessee. Has taught Heat Transfer and Thermodynamics at Brooklyn Polytechnic and is presently completing the requirements for the degree of Doctor of Mechanical Engineering. Has published over twenty articles on gas properties, heat transfer thermodynamics and applied mechanics. Present duties are as Consultant, Nuclear Energy Department, Foster Wheeler Corporation, New York.

In the absence of phase changes, the heat transfer coefficient for liquids or vapors flowing turbulently inside of a tube can be calculated from the well known Colburn Equation (1), one form of which is given by the equation:

$$\frac{hd}{K}=0.023\left(\frac{C_p\mu}{K}\right)^{1/3}\left(\frac{Wd}{\mu a}\right)^{0.8} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

The exponent of the Prandtl number $\left(\frac{C_p\mu}{K}\right)$ has been found by various investigators to be between 0.3 and 0.4. The author has found that Equation (1) above is satisfactory for most engineering calculations. An alternate form of Equation (1) above can be written as:

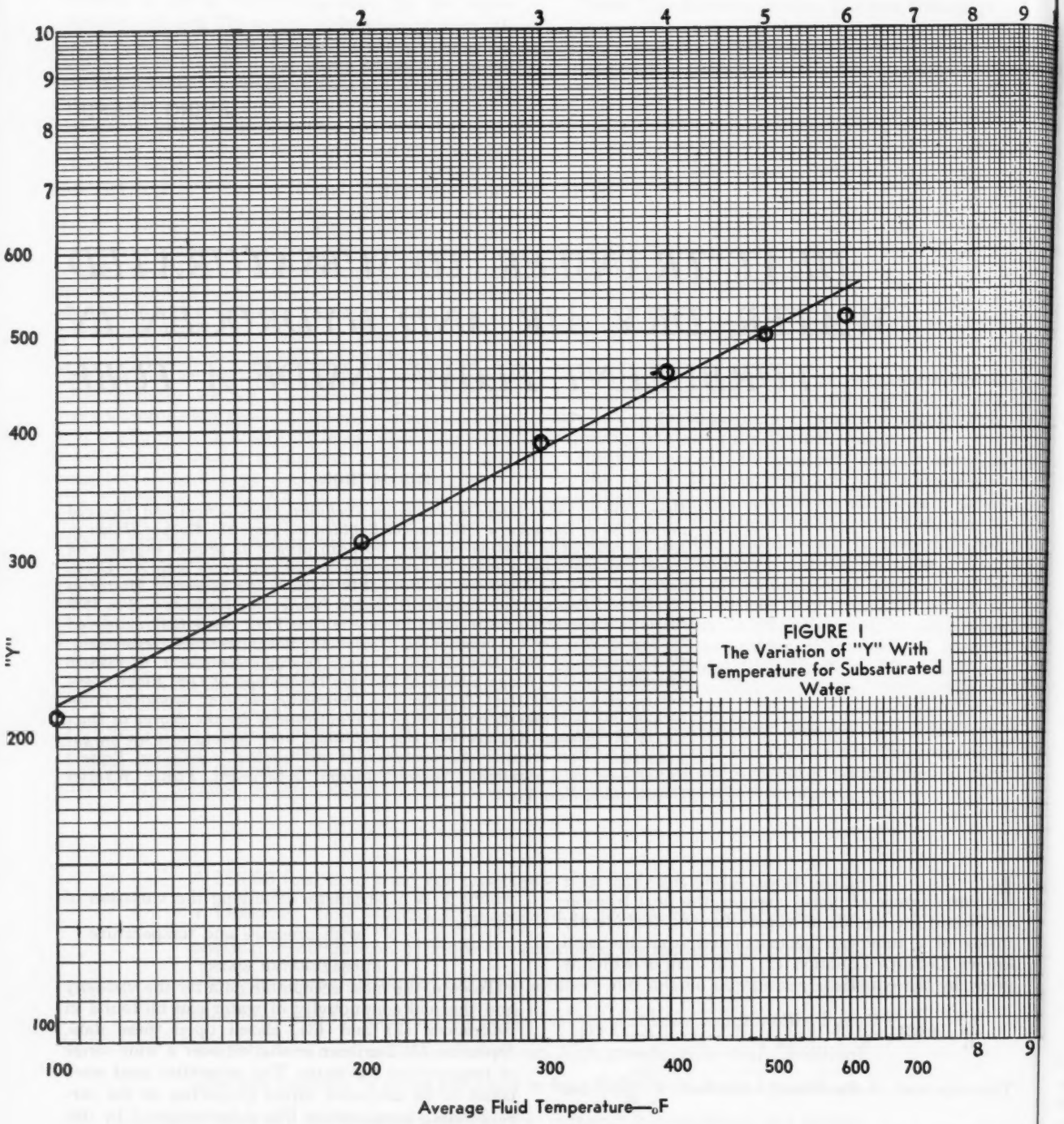
$$hd^{0.2}=Y\left(\frac{W}{1000a}\right)^{0.8} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

where Y is a parameter involving the variation of $K\left(\frac{C_p\mu}{K}\right)^{1/3} \Big/ \mu^{0.8}$ with pressure and temperature.

SUBSATURATED WATER

To date, the most acceptable data for the viscosity and thermal conductivity of water can be found in references (2) and (3). Based upon these data, Equation (2) has been evaluated over a wide range of temperature for water. The properties used were taken to be saturated liquid properties at the corresponding temperature. The error incurred by this procedure is negligible.

A plot of Y against temperature on log-log paper indicates that the resulting function is an exponental with respect to temperature as is shown in Figure 1. The maximum deviation from calculated values of Y is approximately 6 per cent and this only occurs at high temperature values. Evaluating the



constants and rearranging Equation (2) yields:

$$hd^{1.8}=23.7(T)^{0.522}\left(\frac{W}{1000}\right)^{0.8} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Since the Colburn correlation is strictly only applicable for Reynolds numbers of greater than 10,000, it is necessary in all cases to check this dimensionless number before applying any of the foregoing relations. To facilitate the calculation, the viscosity of saturated water has been plotted as a function of temperature in Figure 2. Once it has been established that the flow is in the turbulent state, Figures 3 and 4 enable the designer to rap-

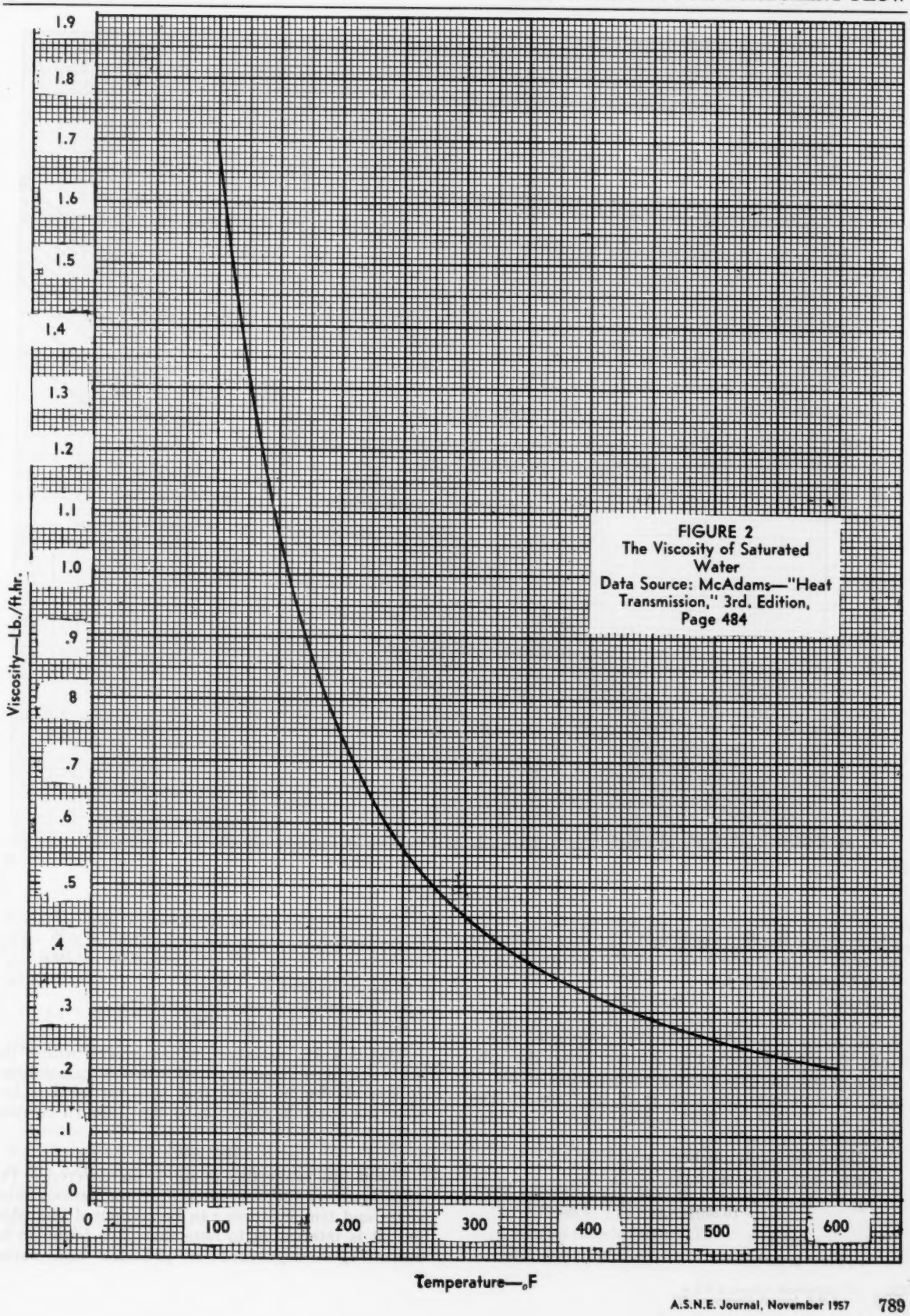
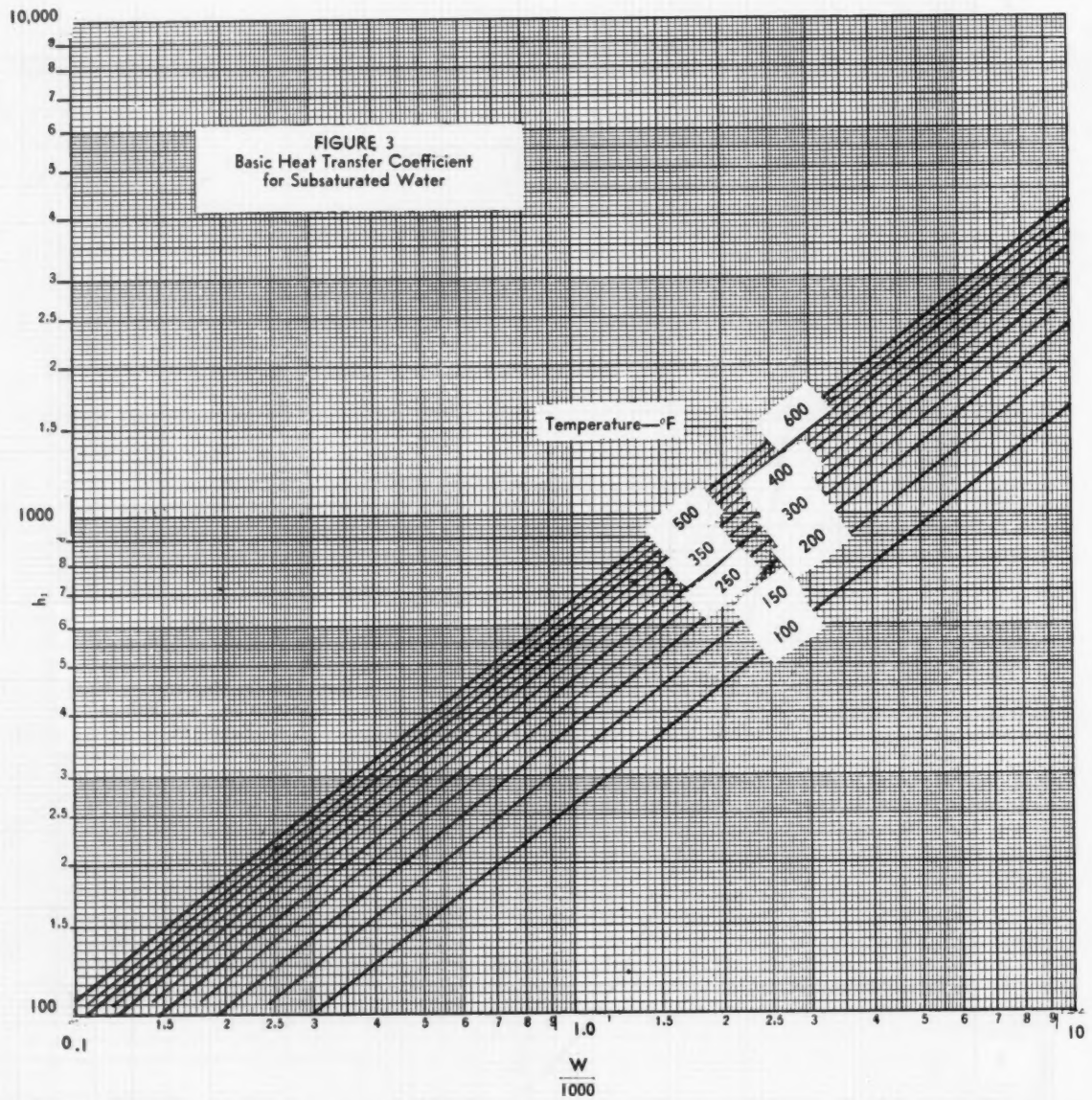


FIGURE 2
The Viscosity of Saturated Water
Data Source: McAdams—"Heat Transmission," 3rd. Edition, Page 484



idly evaluate the film coefficient. The film coefficient referred to the inside surface is the product $F \times h_i$ from Curves 3 and 4.

Example:

A single pass heat exchanger is used to heat a dilute aqueous solution (physical properties essentially those of water). The solution is on the tube side and will have an average temperature of 400° F and the flow rate per tube is 20 lbs./minute. The tubes are 1" O.D. × .065" average wall. Determine the inside film coefficient.

1. Check Reynold's number

$$\frac{dG}{\mu} = \frac{0.87}{12} \frac{(20\times60)\times144}{\frac{\pi}{4}(0.87)^2} \times \frac{1}{0.33}$$ Viscosity from Figure 2

$$= 63{,}700$$

$\therefore$ Flow is turbulent.

2. From Figure 3, $h_i = 630$, where $\frac{20\times60}{1000} = \frac{W}{1000} = 1.2$

3. From Figure 4, $F = 1.25$

4. Therefore $h = F \times h_i = 1.25 \times 630 = 789$

By direct calculation, $h = 820$.

This is a 4% variation, which is well within the accuracy of engineering heat transfer calculations. It should also be noted that this variation is less than the possible variation in the Colburn correlation.

DRY AIR

Using the properties of air from Reference (4) and Equation (2), the value of Y for various pressures and temperatures can be computed and plotted. It is interesting to note that Y is found to be essentially independent of pressure and varies

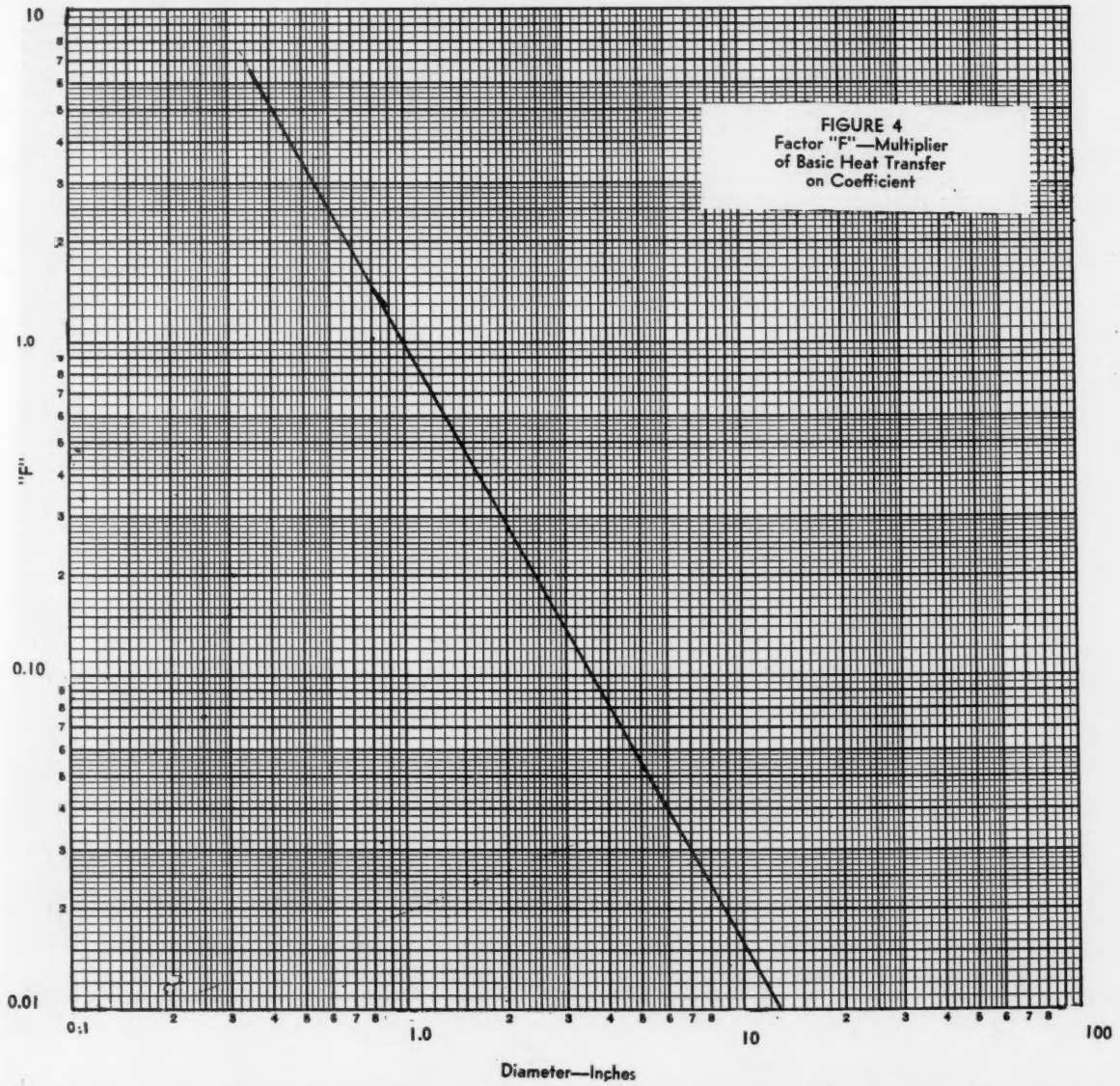


FIGURE 4
Factor "F"—Multiplier of Basic Heat Transfer on Coefficient

linearly with temperature in the temperature range from 300 to 2000° F. The resulting equation for dry air which corresponds to Equation (3) for subsaturated water is:

$$hd^{1.8} = (106.8 + 0.0221T)\left(\frac{W}{1000}\right)^{0.8} \quad \ldots\ldots\ldots\ldots (4)$$

and

$$h = Fh_1 \text{ where } F = d^{-1.8} \text{ and } h_1 = (106.8 + 0.0221T)\left(\frac{W}{1000}\right)^{0.8} \quad \ldots\ldots\ldots\ldots (5)$$

Equation (5) has been plotted in Figure 5. As with subsaturated water, the inside film coefficient is the product of $F \times h_1$. Figure 6 from Reference (4) gives the viscosity for checking the Reynolds number.

Example:

Assume the fluid of the problem for water is dry air at one atmosphere. Calculate the inside film coefficient assuming all other conditions remain constant.

1. Check Reynold's number

$$\frac{dG}{\mu} = \frac{0.87}{12} \times \frac{20 \times 60 \times 144}{\frac{\pi}{4} \times (.87)^2} \times \frac{1}{.0625} = 337{,}000$$

Viscosity from Figure 6

$\therefore$ Flow is turbulent.

2. From Figure 5, $h_1 = 134$, for $\frac{W}{1000} = 1.2$

3. From Figure 4, $F = 1.25$
4. $h = F \times h_1 = 1.25 \times 134 = 168$

By direct calculation $h = 172$
This is an error of less than 3%.

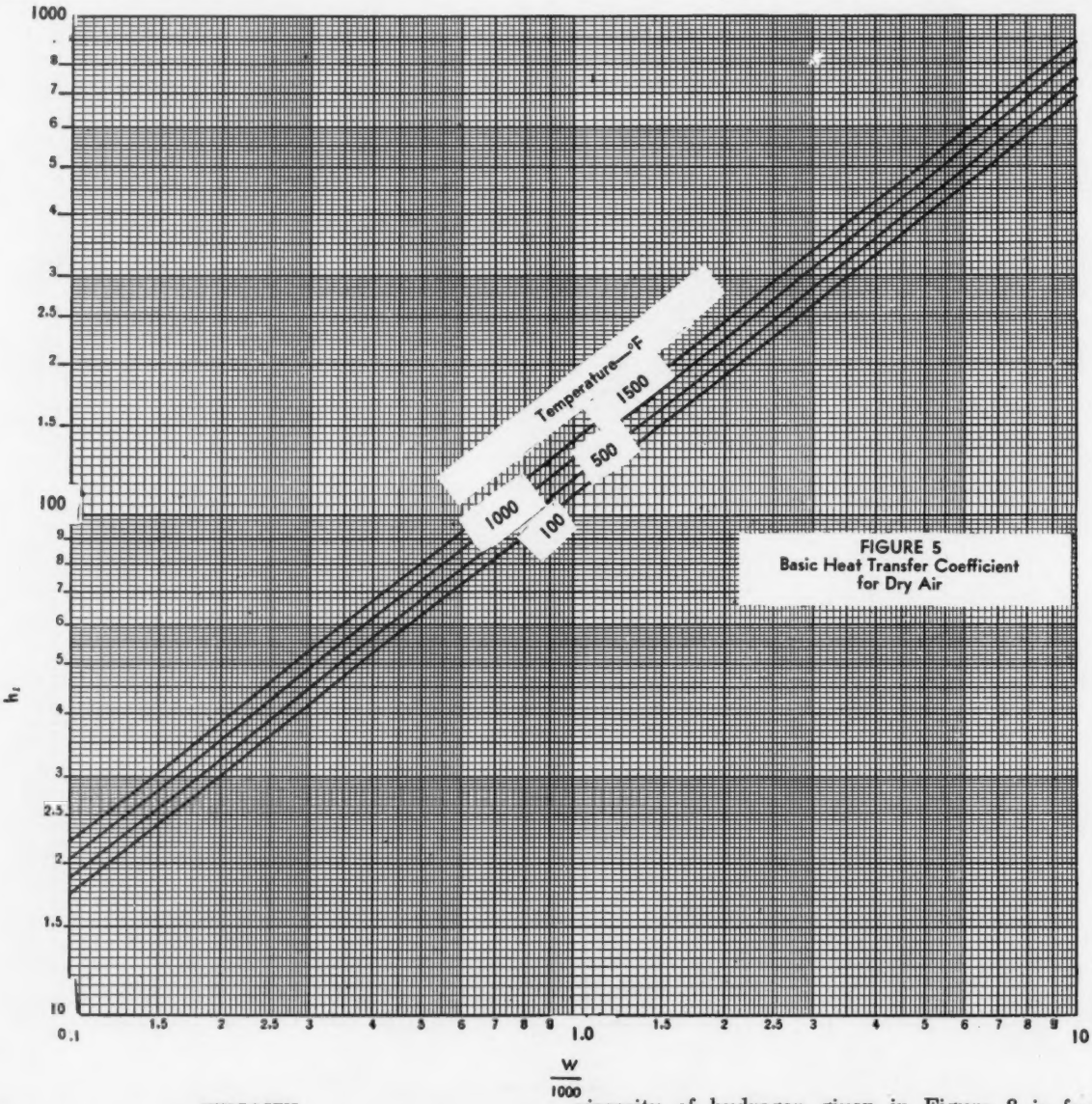


FIGURE 5
Basic Heat Transfer Coefficient for Dry Air

HYDROGEN

The value of Y for hydrogen, based upon the physical properties in Reference (5), exhibits a characteristic similar to water in that it has an exponential dependence on temperature. However, as in the case for air, it appears to be insensitive to pressure and for most engineering calculations may be taken as independent of pressure. Proceeding in the same manner as for water, the following equation can be written for the heat transfer coefficient of hydrogen flowing turbulently inside of a tube:

$$hd^{1.8}=232(T)^{0.181}\left(\frac{W}{1000}\right)^{0.8} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

and

$$h=h_1\times F \text{ where } F=d^{-1.8} \text{ and } h_1=232T^{+0.181}\left(\frac{W}{1000}\right)^{+0.8} \quad \ldots\ldots (7)$$

Equation (7) has been plotted as Figure 7. The viscosity of hydrogen given in Figure 8 is from Reference (5).

Example:

As before assume the fluid in the problem for water is hydrogen at one atmosphere. Calculate the inside film coefficient assuming all other conditions remain constant.

1. Check Reynold's number

$$\frac{dG}{\mu}=\frac{.87}{12}\times\frac{20\times60\times144}{\frac{\pi}{4}(.87)^2}\times\frac{1}{.0296}$$ Viscosity from Figure 8

$$=711{,}000$$

2. From Figure 7, $h_1=790$ for $\frac{W}{1000}=1.2$
3. From Figure 4, $F=1.25$
4. $h=F\times h_1=1.25\times790=990$

By direct calculation $h=1010$

This represents an error of approximately 2%.

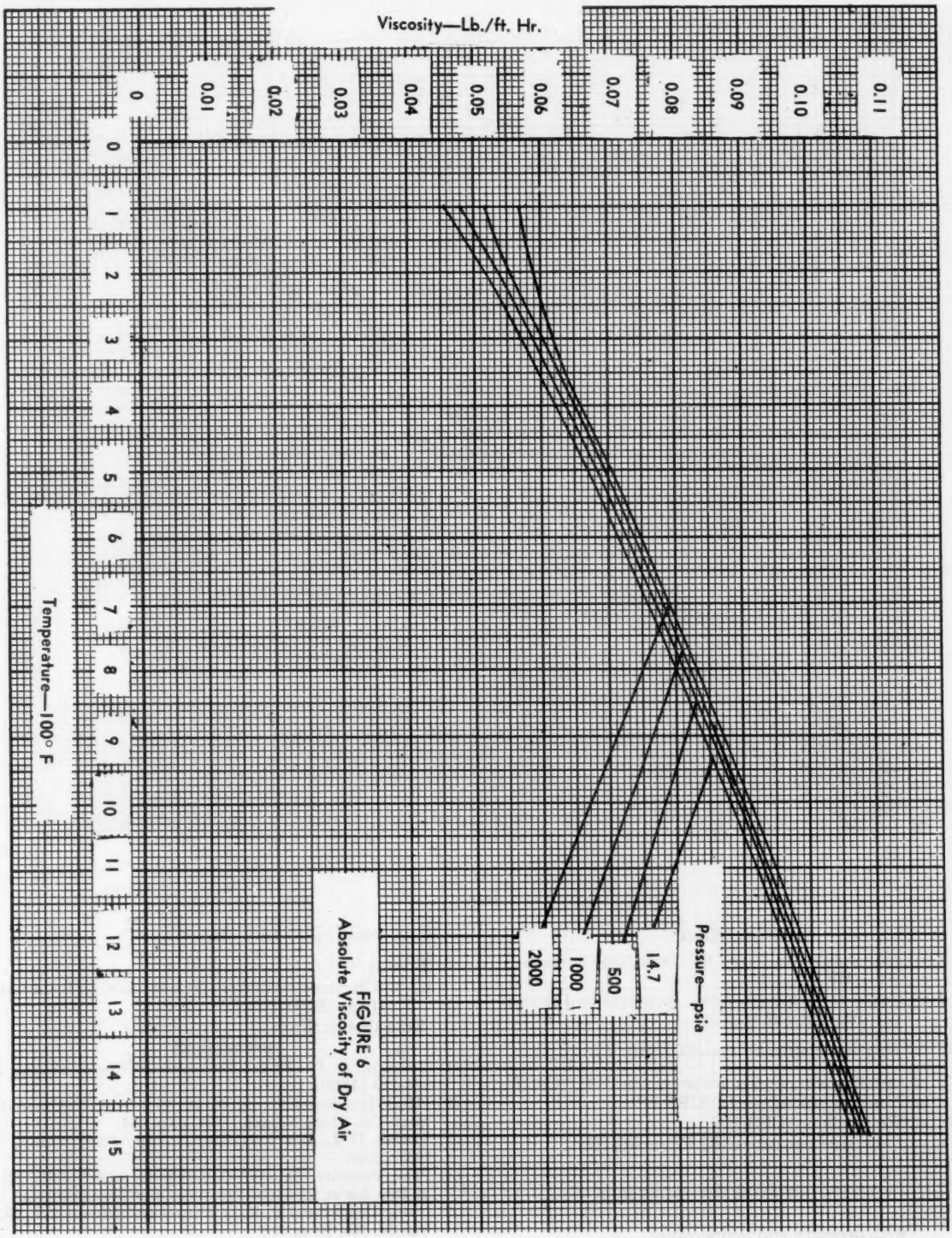


FIGURE 6
Absolute Viscosity of Dry Air

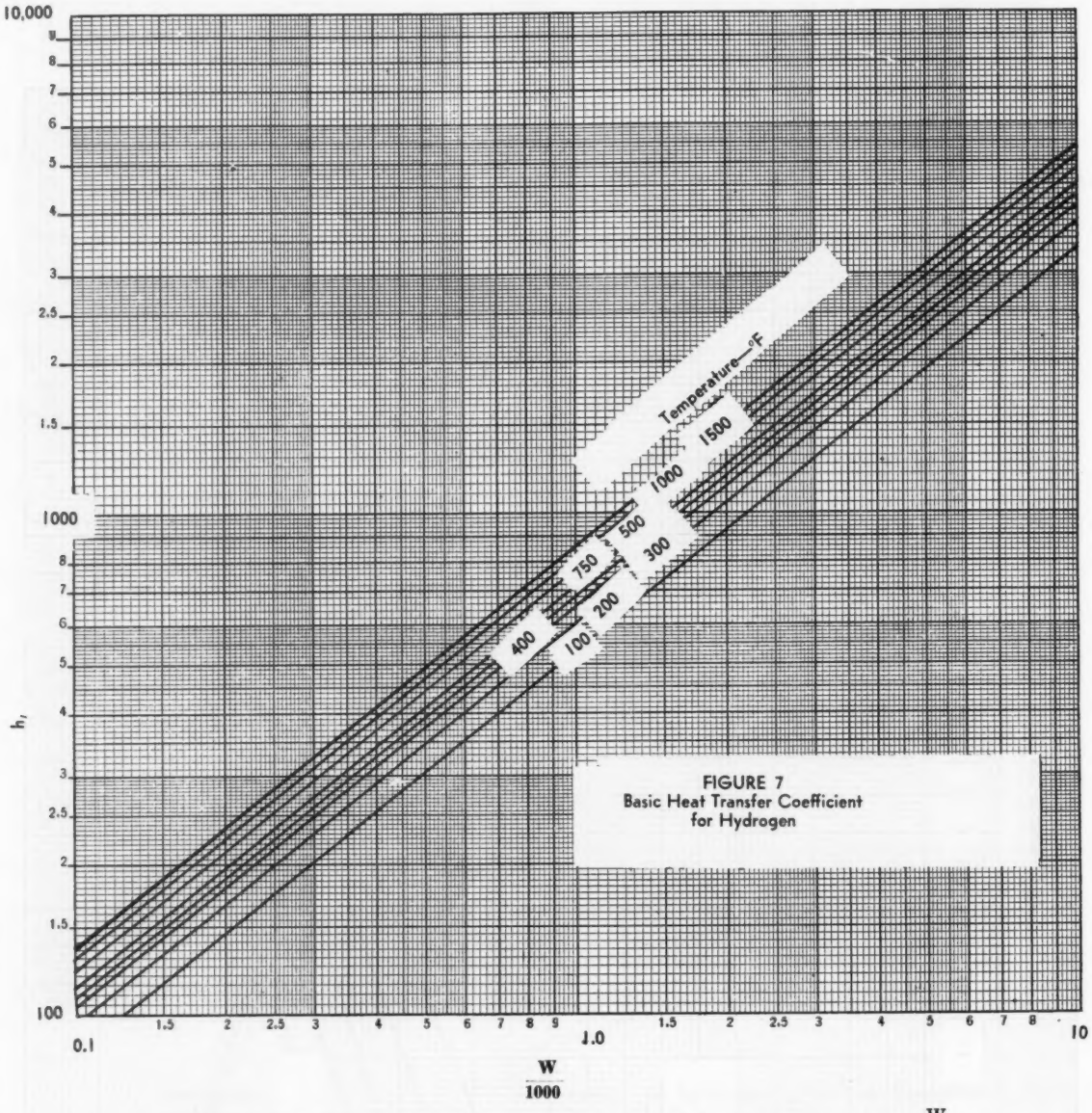


FIGURE 7
Basic Heat Transfer Coefficient for Hydrogen

NOMENCLATURE

h = Film coefficient based on inside tube surface—BTU/HR FT² °F

d = Inside diameter—ft. Note: In equations (2) and (3) this unit is in inches.

K = Thermal conductivity—BTU/HR FT² $\frac{°F}{FT}$

C_p = Specific heat at constant pressure—BTU/LB °F

μ = Absolute viscosity—LBS/FT HR

W = Weight flow—LBS/HR

a = Flow area per tube—SQ FT or SQ IN.

Y = Parameter involving the variation of $K\left(\frac{C_p\mu}{K}\right)^{1/3} / \mu^{0.8}$ with pressure and temperature.

T = Average fluid temperature °F

G = Mass flow—LBS/HR FT² = $\frac{W}{a}$

$F = d^{-1.8}$

h_1 = Uncorrected film coefficient based on inside surface—BTU/HR FT² °F

Note that $h = F \times h_1$.

REFERENCES

(1) Colburn, A. P., Trans. Am. Inst. of Chem. Engrs., 29, 174–210 (1933).

(2) "Heat Transmission," by W. H. McAdams, McGraw Hill Book Co., Third Edition, 1954, page 484.

(3) Timrot, D. L. and Vargaftik, J., Tech. Phys., USSR, 10, 1063 (1940).

(4) "The Viscosity, Thermal Conductivity and Specific Heat of Dry Air at Elevated Pressures and Temperatures," by Irving Granet and P. Kass, Petroleum Refiner, Oct. 1952, Vol. 31, No. 10, p. 113.

(5) "Physical Properties of Hydrogen," by Irving Granet and P. Kass, Petroleum Refiner, May 1954, Vol. 33, No. 5, pp. 205–206.

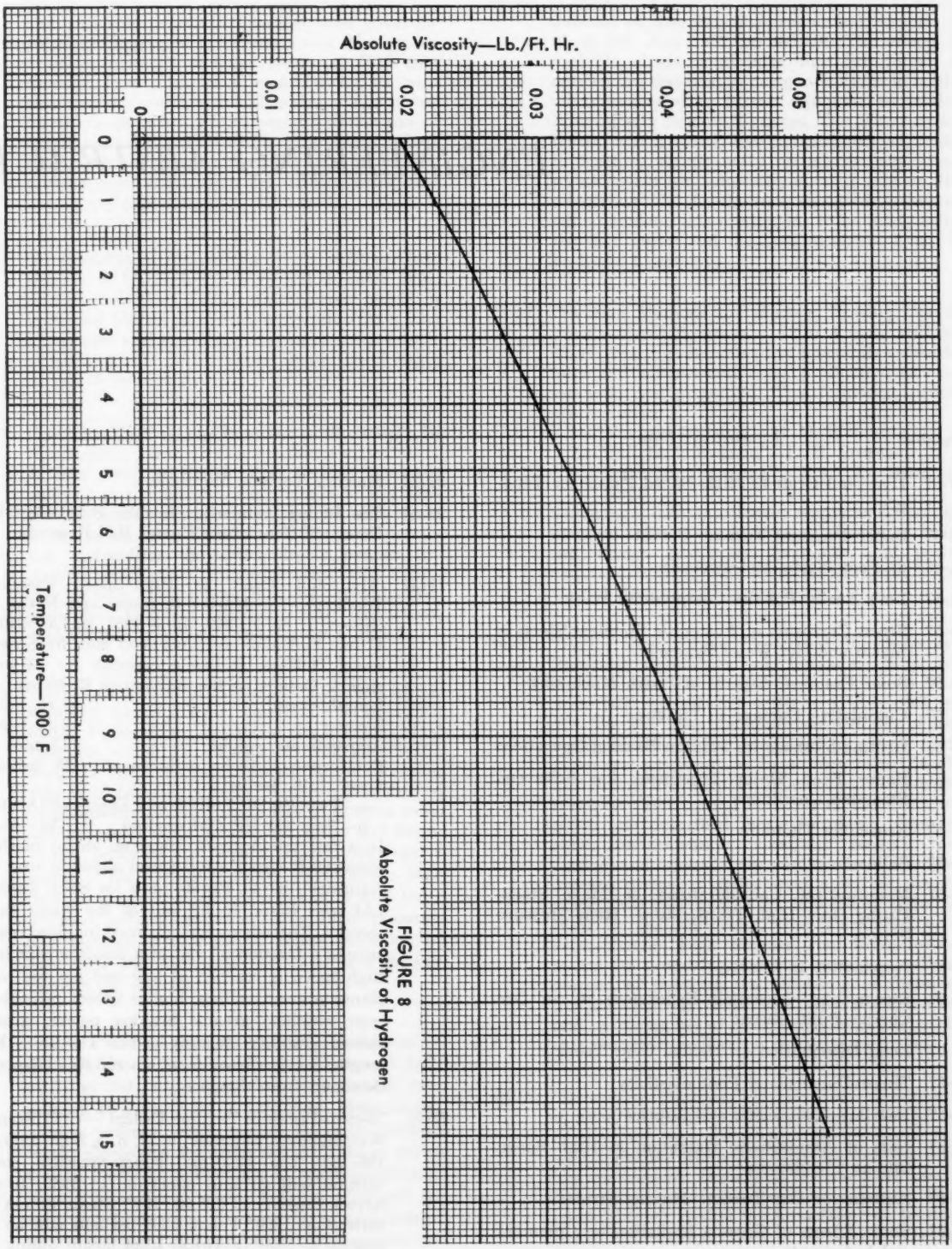


FIGURE 8
Absolute Viscosity of Hydrogen

JOHN W. SAWYER

ENGINEERING ABSTRACTS

Number	*Abstract Title*
71–57	Hydrofoil Craft as High-Speed Passenger Tenders
72–57	Super-Pressure Turbine Design
73–57	57-Foot Plastic Minesweeper
74–57	Let's Really Put the Computer to Work
75–57	Stress Corrosion of Austenitic Stainless Steels in Steam and Hot Water Systems
76–57	Some Practical Aspects of Spark Machining
77–57	Cumulative Damage in Fatigue
78–57	Heating Methods for Modern Brazing Operations
79–57	Boiler Feed Water Treatment for Advanced Steaming Conditions
80–57	Broaching Titanium
81–57	Solions
82–57	Metallurgical Considerations of Main Steam Piping for High-Temperature High-Pressure Service
83–57	Automation in Europe
84–57	Design and Operating Experience of an Ore Carrier Built Abroad
85–57	Load Distribution on Helical Gear Teeth
86–57	Three-Dimensional Photoelasticity
87–57	Bearings, Lubricants and Lubrication
88–57	Role of Atmospheric Oxidation in High Speed Sliding Phenomena
89–57	Automotive Gas Turbine Making Strides
90–57	Some Effects of Gamma Radiation on Commercial Lubricants
91–57	Electronics in Engineering
92–57	Machine Tools in Mothballs
93–57	The Piping Installation for the Burst-Cartridge Detection Gear in the Calder Hall Reactors

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71–57 "Hydrofoil Craft as High-Speed Passenger Tenders"—The Marine Engineer and Naval Architect, v. 80, n. 969, June 1957, pp 207-210. A 47 foot hydrofoil craft has been built by Scheepswerf DeHaas. It has a capacity for 24 passengers. Details on the Aquastroll 23/40 are:

Length overall	47 ft. 1 in.
Beam	12 ft. 6 in.
Approximate weight	13.5 tons
Fuel capacity, 10 hr. endurance	220 gallons
Speed fully loaded	
a—Two 250 HP Rolls Royce Engines	30.8 kts.
b—Two 300 HP GM engines	38 kts.

In a test the Aquavit 5 had an ahead reach of about 60 ft., from a full speed ahead to stop. An Aquastroll 24/40, PL 30, built for Shell Tankers Ltd. was found to lift out of the water in 18 seconds. The advantages claimed include: resistance is a fraction of that of a displacement hull; high speed is reached at low cost per ton mile; planes prevent rolling; higher speeds possible in poor weather; greater braking power; greater maneuverability; turning radius 1½ times boat length; leaves no wake which reduces chance of detection from distance.

72–57 "Super-Pressure Turbine Design"—C. C. Franck; Westinghouse Engineer, v. 17, n. 5, Sept. 1957, pp 156-160. The 5000-psi, super-pressure steam turbine will go into operation in 1959. It will have a capacity of 325,000 KW. Steam enters the turbine at 1200° F and 5000 psi and will be reheated to 1050° F twice. Inlet steam piping incorporates flexible loops to permit thermal expansion between governing valves and turbine

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casing. Steam inlet valves have anti-vibration and anti-spin features. The stop and governor valves are operated by servo motors. The super-pressure element receives steam at 5015 psia through four inlet lines, each having its own stop and governing valve. The first stage is velocity compounded which permits extraction of maximum energy and results in greatest reduction in steam temperature. Turbine case inlet, turbine rotor shaft seals and turbine rotor materials and fabrication are discussed.

73–57 "57-Foot Plastic Minesweeper"—K. B. Spaulding; Bureau of Ships Journal, v. 6, n. 5, Sept. 1957, pp 2-4. A 57-foot plastic minesweeper has been built and placed in operation by the Navy. The techniques and materials developed during construction of the minesweeper should be of value in future construction.

74–57 "Let's Really Put the Computer to Work"—D. D. McCracken; General Electric Review, v. 60, n. 4, July 1957, pp 13-15. Two distinct phases—analysis and synthesis—are common to any system. Extensive use of computers has been made in design analysis. Computers offer great potential in handling the entire design process including engineering, manufacturing and financial factors. Discussion includes optimization, computer facilities, mathematical techniques, organization, personnel and future utilization.

75–57 "Stress Corrosion of Austenitic Stainless Steels in Steam and Hot Water Systems"—C. Edeleanu and P. P. Snowden; Journal of the Iron and Steel Institute, v. 186, Part 4, August 1957, pp 406-422. Much of the work published on stress corrosion relates to laboratory tests. Work was conducted to determine service conditions that were most likely to lead to failures in hot water and steam plants. Included are: testing techniques, experiments in high pressure steam, experiments near dewpoint, effect of aeration, pressure and temperature effects, contamination, high pressure and tests in works steam. Stress corrosion of austenitic stainless steels in steam is a danger under high stresses.

76–57 "Some Practical Aspects of Spark Machining"—J. G. Thirbly; Pametrada News Letter, n. 11, July 1957, pp 2-3. Experimental work on spark machining at Pametrada is discussed. Material includes: process detail; surface finish on finished work; electrodes and their design; rate of penetration methods; application of spark machining. Nozzle plate for a steam turbine produced by spark machining has eliminated costly milling of nozzle segments and end pieces. Photographs included of nozzle plate and a spark erosion machine.

Number *Abstract*

77–57 "Cumulative Damage in Fatigue"—John C. Levy; Journal of The Royal Aeronautical Society, v. 61, n. 559, July 1957, pp 485-491. The effects of variable stress amplitudes that are found in service are essential to designers. Reliable methods are needed to permit designers to predict these effects from S-N curves. The Miner hypothesis, which states the cumulative cycle ratio to fracture equals unity no matter how many stress levels are encountered, may err on the dangerous side. An alternate method is presented which enables safe predictions to be made using the S-N curve and the load spectrum likely to be found in service.

78–57 "Heating Methods for Modern Brazing Operations"—Metal Progress, v. 72, n. 1, July 1957, pp 65-76. Brazing methods—fits, assemblies, cleanliness and alloys—and mass production heating methods are presented. The following papers are included:

1—"Furnace Brazing"—H. M. Webber
2—"Salt Bath Brazing"—L. B. Rossean
3—"Induction Brazing"—Wm. E. Benninghouft.

The papers contain: furnace equipment, work on electron tubes, vacuum brazing, aluminum brazing, design economies, examples, and power required. Brazing techniques result in simplification of designs and lower costs.

79–57 "Boiler Feed Water Treatment for Advanced Steaming Conditions"—J. Leicester; Ship and Boat Builder and Naval Architect, v. 10, n. 6 June 1957, pp 207-209, v. 10, n. 7, July 1957, pp 257-260. The need for improved methods of feed water treatment has increased as steam pressures and temperatures have been raised to obtain higher overall plant efficiencies. Feed-water treatment and testing methods in use are compared and described. Scale formation, deposits, solids concentration, alkalinity control, feed testing and controls are reviewed. A dissolved oxygen meter is under evaluation on several ships. Two instruments are now being tested on ships by the Admiralty. One is installed on a cross-channel boat. Results from these instruments are promising and may provide a reliable method of showing the efficiency of dissolved oxygen removal from feed systems. Efficiency and operating life of boilers may be improved by this use which will aid in reducing corrosion.

80–57 "Broaching Titanium"—L. B. Gray; Machinery, v. 63, n. 12, August 1957, pp 135-141. Machining of titanium does not present the problems that were expected when this material was first finding applications. Broaching is considered one of the difficult machining operations by some. With special broach design the broaching can be done easily and surface finish of 32 micro-inches or smoother can be realized. Insert type broaches, while more expensive initially, may be modified

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easily to accommodate design changes in compressor disc and blades.

81–57 "Solions"—Machine Design, v. 29, n. 17, August 20, 1957, pp 102-105. A new and revolutionary electrical control element has been developed by the United States Navy for ordnance use. The element, an electrochemical transducer, is highly sensitive to heat, pressure, sound, motion and light. An electric current is generated in the device when ions are caused to move through an iodine solution between two electrodes. Initial current flow is excited by a low-voltage dry cell battery placed in series with the solion. This current is varied by outside stimulation of the solion according to changes in temperature, pressure, light, motion and sound. The solion is expected to find many commercial applications. Present and future applications include: use in rate circuits or derivative units; integration units; flight integrators; thermostat control and sound exposure meter for measuring cumulative exposure of personnel to engine noise.

82–57 "Metallurgical Considerations of Main Steam Piping for High-Temperature High-Pressure Service"—H. S. Blumberg; Transactions of the American Society of Mechanical Engineers, v. 79, n. 6, August 1957, pp 1377-1397. Approach to the problem of selecting material is presented. Piping materials currently in use are discussed, including the Eddystone 1200°F, 5600 psi plant. Discussion, photographs, tables and bibliography.

83–57 "Automation in Europe"—T. W. Black; The Tool Engineer, v. XXXIX, n. 3, Sept. 1957, pp 73-77. Automation was discussed by representatives of countries of Western Europe at a Paris meeting. Progress has been made in this field. Not many standard machine tools are equipped with automatic features. Centerless grinders have some feedback controls for self-correction. Tape controlled milling machines have been developed. Work on automatic assembly machines has resulted in development of a number of machines. Effects of automation have raised problems. Displacement of labor due to automation is not acute. It has created a need for training skilled personnel. Automation offers lower production costs. Increased use of automation is expected in the next few years.

84–57 "Design and Operating Experience of an Ore Carrier Built Abroad"—R. Atkinson; The Institute of Marine Engineers Transactions, v. LXIX, n. 7, July 1957, pp 261-306. The ore carrier T. S. S. *Sunrip* was built by Davie Shipbuilding Co., Ltd., Quebec. Material includes the following: hull layout with machinery amidships and aft; distribution of water ballast; speed and type of machinery; location of propelling machinery; principal characteristics; uses of aluminum; fitting-out details; considerations of A. C. and D. C. systems; selection of propelling machinery; operating experience. In selecting the propelling machinery studies were conducted on reciprocating engines, direct drive diesel, geared diesel, geared turbine and turbo-electric. Comparative weights, costs, and fuel consumption curves are shown. Steam turbine machinery was finally selected because of: lower maintenance; difficulty of diesel maintenance at ports of call; less weight and availability of desired fuel. In the discussion fuel consumption curves for a free-piston gas turbine plant are compared with those of steam turbines and diesel.

85–57 "Load Distribution on Helical Gear Teeth"—M. D. Trbojevic; The Engineer, v. 204, n. 5298, August 9, 1957, pp 187-190; v. 204, n. 5299, August 16, 1957, pp 222-224. Work was conducted at the University of Sheffield and the University of Belgrade to investigate deflections and load distribution lines on a rubber tooth under various load conditions. Experimental work, test equipment, the rubber tooth, method of testing, analysis of data and reliability of results are presented. Research conducted shows: load distribution on contact line is somewhat uniform; difference between mean and maximum load did not exceed 2.2 per cent; gears with short helices are not as satisfactory as spur; most favorable helix is that angle where combined deflection is minimum for a specific load. Curves, photographs, diagrams, references.

86–57 "Three-Dimensional Photoelasticity"—M. M. Leven; Product Engineering, v. XXVIII, n. 7, July 1957, pp 135-140. Stress distributions in turbine discs, flanges, pressure vessels and other intricate shapes can be determined accurately by the frozen stress method. A plastic model of the part under consideration is heated to the critical temperature and loaded. It is then cooled with load still applied. When the plastic reaches ambient temperature loads are removed. The strains are locked in the plastic and show elastic distribution of stress. The model can be sectioned. These sections will retain the stress distribution patterns and can be analyzed with darkroom facilities and a diffusion circular polariscope camera. Most suitable casting materials are acid-cured epoxy resins. Techniques of casting and analysis of results are discussed. Photographs, tables, illustrations and related publications.

87–57 "Bearings, Lubricants and Lubrication"—Mechanical Engineering, v. 79, n. 9, Sept. 1957, pp 842-852. This is a report prepared by H. A. Hartung, assisted by the Research Technical Committee of the ASME Lubrication Division. The summary of the 1956 literature includes: journal bearings, thrust bearings, gears, rolling element

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bearings, boundary lubrication, metalworking lubrication, automotive lubricants, properties of lubricants, books and a bibliography of 163 items.

88–57 "Role of Atmospheric Oxidation in High Speed Sliding Phenomena"—M. Cocks; Journal of Applied Physics, v. 28, n. 8, August 1957, pp 835-843. The effect of oxidation in inhibiting interaction between metal surfaces sliding at high speeds with respect to each other has been investigated. Results of tests are presented. It was concluded that at light loads metal surfaces showed severe tearing. Tearing was nearly eliminated from at least one of the surfaces under high speeds and above certain loads. The reduced tearing was due to the increased surface oxidation associated with frictional heating. At high loads severe wear resulted from oxide disintegration. High temperatures reduce friction and tearing. They cause accelerated wear at high loads. Reference, photographs, curves.

80–57 "Automotive Gas Turbine Making Strides"—G. J. Huebner, Jr.; SAE Journal, v. 65, n. 8, July 1957, pp 72-75. The regenerative gas turbine shows excellent promise of becoming the power plant of the future ground vehicle. The present gas turbine strongly rivals conventional piston engines and methods for further improving cycle efficiency are known. An improvement of thermal efficiency to 40% is considered possible within the next ten years. The present Chrysler gas turbine engine has a brake specific fuel consumption of about 0.43 lb. per hr. at 100 per cent power. Future developments can reduce this fuel consumption to about 0.39 lb. per bhp-hr. Compressor and turbine efficiencies are steadily increasing. Cost reduction is being realized through design and manufacturing techniques.

90–57 "Some Effects of Gamma Radiation on Commercial Lubricants"—J. G. Carroll and S. R. Calish, Jr.; Lubrication Engineering, v. 13, n. 7, July 1957, pp 388-392. With the rapid increase in the number of reactors (45 constructed to date and 127 additional expected by 1960) lubricants are under investigation, to determine their suitability for use in nuclear plants. Some twenty-eight lubricants, four base oils, four industrial oils, gear lubricants, transmission fluids, industrial greases and multipurpose greases were exposed to gamma rays. Results of the tests are shown. Data indicate: some commercial oils and greases can be used provided gamma dosages do not exceed 10^8r; the effect on lubricants is somewhat like oxidation; wear properties and load carrying capacities are improved.

Number *Abstract*

91–57 "Electronics in Engineering"—D. S. Gordon; Transactions of the Institution of Engineers and Shipbuilders in Scotland, v. 100, Part 5, 1956-57, pp 465-504. A presentation of the history of industrial electronics and the buildup of electronic devices from basic units. Applications that are of interest to engineers and naval architects are: speed control, excitation and detection apparatus, position control, automatic inspection and testing. Physical characteristics such as color, density, resistance and permittivity, can be measured electronically. Illustrations, references and discussions.

92–57 "Machine Tools in Mothballs"—R. L. Hamm and G. A. Kelly; American Machinist, v. 101, n. 16, Aug. 12, 1957, pp 124-127. The General Services Administration techniques for preserving and storing government owned machine tools that may be required for use in a future emergency are outlined. Standby storage, extended storage, spray-booth cleaning, record forms, cleaning internal surfaces, preservation and storage methods are reviewed. Rust inhibiting oils, paper, preservatives, vapor barrier material and other materials used are mentioned with specification numbers.

93–57 "The Piping Installation for the Burst-Cartridge Detection Gear in the Calder Hall Reactors"—J. M. Laithwaite; British Welding Journal, v. 4, n. 8, August 1957, pp 360-367. Calder Hall reactors contain 10,176 cartridges. A cartridge consists of an uranium bar sealed in a leak proof container. In the event of a can failure radioactive material can be released into the reactor circuit. A cartridge burst detection system to give warning of a failure has been provided. The system design, joining techniques, material, equipment and installation are described. The detection piping system includes some 12,000 brazed joints and approximately 45 miles of piping. During the installation an average of 62 joints were made per day in the vessel. A total of 111 joints failed out of 12,000 under leak tests.

THE publishers, with addresses, of the periodicals from which the above abstracts were prepared are presented below. This information is provided for the convenience of readers of The Journal who wish to obtain complete copies of papers abstracted. The numbering system below corresponds to the abstract numbering system.

71–57 Whitehall Technical Press, Ltd.
9 Catherine Place
Westminster
London, S.W. 1, England

72–57 Westinghouse Engineer
P. O. Box 2278, 3 Gateway Center
Pittsburgh 30, Pa.

Number *Abstract*

73–57 Bureau of Ships Journal
Bureau of Ships
Department of the Navy
Washington 25, D. C.

74–57 General Electric Co.
Schenectady 5, N. Y.

75–57 Journal of the Iron & Steel Institute
4 Grosvenor Gardens
London, S. W. 1, England

76–57 Pametrada Research Station
Wallsend
Northumberland, England

77–57 The Royal Aeronautical Society
4 Hamilton Place
London, W. 1, England

78–57 American Society for Metals
Mt. Morris, Ill.

79–57 John Trundell (Publishers) Ltd.
Temple Chambers
Temple Avenue
London, E. C. 4, England

80–57 The Industrial Press
93 Worth Street
New York 13, N. Y.

81–57 Machine Design
Penton Building
Cleveland 13, Ohio

82–57 The American Society of Mechanical Engineers
29 West Thirty Ninth Street
New York 18, N. Y.

Number *Abstract*

83–57 American Society of Tool Engineers
239 E. Chicago Street
Milwaukee, Wisconsin

84–57 The Institute of Marine Engineers
85 Minores
London, E. C. 3, England

85–57 The Engineer
28 Essex Street, Strand
London, W. C. 2, England

86–57 McGraw-Hill Publishing Co.
330 West 42nd Street
New York 36, N. Y.

87–57 The American Society of Mechanical Engineers
29 West Thirty Ninth Street
New York 18, N. Y.

88–57 American Institute of Physics
335 East 45th Street
New York 17, N. Y.

89–57 Society of Automotive Engineers, Inc.
29 W. 39th Street
New York 18, N. Y.

90–57 American Society of Lubrication Engineers
84 E. Randolph Street
Chicago 1, Ill.

91–57 Institution of Engineers & Shipbuilders
Elmbank Crescent
Glasgow, Scotland

92–57 McGraw-Hill Publishing Co.
330 West 42nd Street
New York 36, N. Y.

93–57 British Welding Journal
Grosvenor Gardens
London, S.W. 1, England

Discussion by

Laskar Wechsler

of

Selection of Diesel Propulsion Plants for Naval Vessels

by James J. Turner, JASNE, August 1957

I WOULD like to comment on Mr. James J. Turner's paper "Selection of Diesel Propulsion Plants for Naval Vessels" in the August 1957 issue of the JOURNAL of the A.S.N.E. Mr. Turner presents a very interesting and desirable approach to the proper selection of diesel engines for marine propulsion. When he gets into the field of diesel design and performance as covered in figures 4, 7, 8, 9, 10 and 11, Mr. Turner has drawn conclusions which cannot be sustantiated as general criteria, though they may, in some instances appear to be correct if a very limited number of engines are considered.

Specifically, figure 4 shows fuel consumption curves which might be interpreted to mean that naturally aspirated engines between 1000 and 2000 BHP are more efficient than those over 2000 BHP. By the same token it is implied that supercharged engines between 1000 and 3000 BHP are less efficient than those over 3000 BHP. Actually these performance maps are representative of individual engines and if additional engines were considered it would become evident that fuel consumption generalization by engine size, cycle, degree of supercharge is not possible.

The trend shown in figure 7 for weight in pounds per horsepower versus bore, must be used with caution inasmuch as a relatively few engines are plotted. Two stroke and four stroke engines do not have the same characteristics. The two stroke engine usually is larger than the four stroke for the same bore, however, it can produce more power. Another factor which has been ignored is that the same bore engine in increased number of cylinders will show a decrease in specific weight.

The curve of figure 8 is particularly misleading inasmuch as BMEP for both 2 and 4 stroke cycle engine are plotted on the same curve against bore. The lowest points in the curve at a BMEP of about 85 are all two stroke engines; in which case the conclusion to be drawn would be that BMEP remains about the same or slightly increased with increase in bore size. The points in the upper part of the chart cover turbocharged four stroke engines and in this case show that BMEP decreases somewhat with bore inasmuch as the heat generated would increase directly with the volume, or bore cubed, while the heat dissipating surface increases directly as the bore squared. It is therefore necessary to reduce BMEP, or heat release per unit of volume as the bore size increases. This reduction would not be as much as shown by figure 8, if engines of the same vintage were used. The two points at about 125 psi BMEP represent turbocharged two stroke engines which should be considered separately from the other two classes.

There is little justification for the curve drawn in figure 9 in view of the points plotted. It appears that several lines could be drawn parallel to the bore axis which would indicate that for a certain class of duty, piston speed does not vary with bore. Inertia forces are proportional to piston speed, and remain constant with bore at the same piston speed, which is further reason to doubt the curve as drawn in figure 9.

In figure 11 an attempt is made to relate specific weight to total displacement of engines by grouping them as over and under 1000 RPM. The scatter can be explained very easily by the wide range in RPM, and BMEP of the engines representing the plotted points. A reasonably good curve could be plotted of weight per cubic inch versus displacement. This would then have to be divided by horsepower per cubic inch to obtain specific weight. Horsepower per cubic inch is a function of BMEP and engine speed as shown by the formula:

$$\text{Horsepower} = \text{Constant} \times \text{BMEP} \times \text{Displacement} \times \text{RPM}$$

or

$$\frac{\text{Horsepower}}{\text{Cubic inch}} = \frac{1}{K} \times P \times N$$

Therefore we would expect that the specific weight would vary at any displacement, depending on the BMEP and RPM of the engine in question.

I believe that Mr. Turner did an excellent job on the subject of selecting diesels to match ship's characteristics. He did not do as well in explaining the why and wherefore of engine design.

The author comments on Mr. Wechsler's discussion in the following letter.

"Secretary-Treasurer
The American Society of
Naval Engineers Inc.

Dear Mr. Hamilton:

I received a copy of Mr. Wechsler's comments on by paper 'Selection of Diesel Propulsion Plants for Naval Vessels.'

It was never my intention to enter the diesel engine design field with my paper and for that reason I did not discuss engine design as such. Figures 7, 8, 9, 10 and 11 were qualified in the paper as being based on engines studied by me for propulsion application over a one year period and represent what was offered by the manufacturers and approved for naval application. All the curves were accompanied by the points from which they were derived because of the limited number of engines studied.

It was not my intention to imply any significance to the performance maps given in figure 4 other than that they vary greatly in shape and value from engine to engine. A discussion of the why and wherefores of the fuel consumption curves would result in a paper much larger than the brief one given by me.

I do regret that I did not further identify the points used in figure 8.

Mr. Wechsler's comments are appreciated and were reviewed with interest and in general are a desirable addition from the standpoint of why and wherefore.

Sincerely,

JAMES J. TURNER"

JJT: mac

BOOK REVIEWS AND NOTICES

HYDRODYNAMICS IN SHIP DESIGN

by

Captain Harold E. Saunders USN (Ret.)

Published in 1957 by

The Society of

Naval Architects and Marine Engineers

74 Trinity Place

New York 6, New York

Volume I: 37 Chapters, 615 pages of text, 420 illustrations

Volume II: 39 Chapters, 932 pages of text, 463 illustrations

$30.00

Reviewed by

Robert Taggart

Director, Experimental Test Division

Reed Research, Inc.

Hydrodynamics in Ship Design is a story—a story of ships and the environment in which they live. The intricate interrelationships between water and the underwater body of a ship are subtle and mysterious, but in this story the subtleties are vividly described and the mysteries are ingeniously unraveled.

The book covers exactly the subject which its title suggests, no more. And yet, this authoritative work is the most thorough and complete treatment of the subject which has ever been written. Starting with the basic principles of liquid flow and developing through to the complete hydrodynamic design of a ship, every possible facet of liquid motion around the hull, appendages, and propulsive device is considered in a most comprehensive manner. The step-by-step story of how observation, analysis, and theory have combined in developing an understanding of hydrodynamic flow unfolds with fascinating detail and insight.

The story begins with a delineation of the types of flow which can develop around a ship including potential, viscous, hydrofoil, and elastic flow and the phenomena of separation, cavitation, circulation, and wavemaking. The characteristics of the liquid itself are then described including aspects of its behavior under varying physical and environmental conditions. This description leads then to the basic forms of flow phenomena which underlie all forms of hydrodynamic behavior in both real and ideal liquids.

To introduce the reader gradually to the intricacies of flow around ships, several cases of the flow of an ideal liquid around a two-dimensional ship form are considered with the velocity and pressure distributions explained. Then the behavior of a real liquid along a flat surface is described showing what takes place in the development of a boundary layer and the behavior of water particles when moving over both smooth and rough surfaces including the reciprocal effect of the liquid on the surface. The complexities which are introduced when the surface becomes curved, stem logically from this discussion.

The failure of the liquid to follow the curved surface of a ship form results in separation and cavitation. These phenomena, the conditions which create them, and the resulting effect on the body, are carefully explained. When discontinuities such as pipes, ducts, or scoops are introduced into the hull surface they disturb the flow in many ways. Or when water or a gas is discharged underwater the surrounding flow is disturbed with effects which react on both the internal and external flow.

One of the most predominant sources of ship resistance is the surface wave which the body generates. First the phenomenon of wave propagation at the air-liquid interface is described, and then the creation of waves by a ship form are explained. This explanation includes the various wavemaking sources, the interference patterns of waves which are set up, and the effect of these combined waves on the ship itself.

The disturbance which a ship creates in surrounding liquid takes on many forms. These include the water which is pushed ahead by the bow, pushed backward by the sides, and dragged along behind the hull. The elements which make up this wake around a simple ship form are explained including the components and directions which it assumes in and around the positions of propulsive devices and control surfaces. The summation of the forces which all of these preceding motions of the liquid generate on the ship itself are then delineated.

Differing to some extent from the forces which act on a displacement form are those which act on a planing form or hydrofoil. These forces are treated separately in a manner which makes these complex phenomena much more understandable than texts which have dealt with them in the past.

This understanding of the forces on hydrofoils is extremely helpful in the transition to thrust producing devices which are such an important factor in ship design. The author demonstrates how thrust is produced by each of the basic forms of propulsion devices including paddles, paddle wheels, sculling blades, flexible fins, gas and liquid jets, actuator discs, screw propellers, and rotating-blade vertical-axis propellers. The action of a screw propeller is treated with more detail, first its action in open water, and then the manner in which it behaves when placed behind a simple ship form.

After treatment of the general aspects of ship propellers, the author returns to a description of some of the more complex types of flow around ship forms. This includes the flow around a ship in shallow and restricted waters, and its effect on propulsion and maneuvering. Nonsymmetrical flow around a ship is considered, which takes into account both asymmetry of the hull, and its propulsive or maneuvering devices, or conditions external to the ship. Finally some of the secondary aspects of flow are described, such as spray and bubble formation, the roach and rooster tail, flow around abovewater obstructions, flow through flooding holes, and the flow around a vibrating ship.

The preceding story gives the reader a general concept of flow around a ship, and its propulsion devices. This description of the useful aspects of liquid flow comprises Part 1 of the book. These phenomena are clarified without the usual complicated mathematics, but in a descriptive form with a large number of illustrative elementary diagrams. Part 2 expands upon these phenomena and deals more specifically with their effect on an actual ship form. The transition from idealized to actual conditions is made clear by a description of what takes place around a real ship as related to the simplified assumptions made earlier.

The combined potential and frictional flow around an actual ship are succinctly delineated. First a description of the appearance of the boundary layer around the hull and appendages is given showing the viscous forces which act on both smooth and rough surfaces, as well as curved surfaces of the hull form. Separation and cavitation are discussed for hulls, appendages, and propulsive devices, and the effect of these phenomena on the bodies around which they occur are described.

The interrelationship between hull form and the resulting flow patterns involve detailed consideration of hull form coefficients, the shape of waterplanes and sections, the fore and aft distribution of buoyancy, and the longitudinal curvature of the hull. Various features of the underwater body, such as the bow shape, the shape of sections, and the stern configurations are shown to affect the flow patterns as do special shaping of the hull to include tunnel sterns, contra-guide sterns, bulb bows, and multiple hulls.

The abovewater body is also shown to influence performance. Such factors are considered as bow flare, upper waterline slopes, tumble home, bow and stern profiles above the water, and deck edges and bulwarks. In submarines the abovewater body is of special concern, and in all types of vessels, the wind action on the hull and superstructure are shown to have a demonstrable effect on performance.

The flow characteristics around special types of hull forms are described, including straight-element forms and discontinuous forms. The former are of particular concern in small craft, and the methods of designing developable forms are discussed in detail. The latter are of concern in all types of marine craft, and thus the resulting flow and resistance effects around blisters, bulges, coves, and chines are thoroughly covered. The effect of the running attitude of a ship is also discussed, showing what happens to the flow patterns when the ship is overdraft, trimmed, heeled, or running in a damaged condition.

The design problems in small boats are usually overlooked in naval architectural treatises, and certainly their designer must look far and wide to obtain a real understanding of their hydrodynamic behavior. In this book, the behavior of planing craft and of hydrofoil supported craft are treated in a fundamental manner. Their performance is covered in such a way that the reader obtains an excellent picture of the flow phenomena which exist and which lend dynamic support to these craft at high speed.

The various types of ship propulsion devices described earlier are next analyzed, describing how thrust is obtained and the advantages and disadvantages of each for propelling different types of ships and marine craft. The interaction of the propulsion device, the hull, and the appendages are discussed, together with the relative location of these components and the concomitant results on ship performance. This leads to an analysis of propulsive efficiency as affected by propeller, hull, and propulsion augmentation devices and techniques.

The behavior of actual ships in restricted waters is then taken up. This expands on the basic descrip-

tion given in the first part of the book, and covers practical cases of ship and barge action over bars, in channels, and through locks.

Part 2 concludes the first volume with a discussion of the effect on ship performance of fixed and movable appendages including shafting, bossings, struts, contra-propellers, bilge keels, shrouding on propellers, scoops, speed measuring devices, sound domes, rudders, diving planes, rotating-blade propellers, and centerboards.

The first volume is a readable exposition on hydrodynamic theory as applied to ships. It is essential background information on flow phenomena which should be read and understood before utilizing the more detailed design information given in the second volume. The book has been so organized that once the information in the first volume has been assimilated, it can be laid aside and the second volume used by itself as a reference text for designers.

Of particular note, are the appendixes to both Volumes I and II, which contain first a list of symbols and their titles. The principal symbols are in conformance with those adopted by the American Towing Tank Conference, and many of them have been adopted by the Sixth International Conference of Ship Tank Superintendents as a tentative standard. The work on summarizing these symbols, of eliminating redundancies, and of encouraging their adoption has been an important by-product of this book and a credit to its author.

Following a theme written long ago, the author has "enlightened us, with due proportion, on men as well as on things." In addition to copious references to contributors to the science throughout the text, appendixes in both volumes contain personal name indexes. Subject indexes and ship name indexes are also included, and adequate cross references are given in both volumes.

Volume II and Part 3 begins with an exposition of the basic concepts underlying all calculations and predictions, and general liquid flow formulas. This illustrates the relationship between the mathematical approach and the empirical approach to the design of a ship. Admittedly, naval architecture is a mixture of art, science, and experience. But the author points out how, as mathematical and theoretical concepts are developed, they can gradually replace those phases of ship design which are still based on art and empiricism. Those liquid-flow formulas which are now applicable to ship design are listed, and their application to design is indicated. Potential flow patterns, velocity and pressure diagrams for various bodies, information on source-sink diagrams, and theoretical consideration of hydrofoil action further indicate how theory can be applied to some phases of the ship design problem. This is supported by voluminous references to more detailed texts on these subjects.

Frictional resistance is discussed not only as a gross effect on the entire ship, but the complete make-up of the boundary layer is treated for both hydrodynamically smooth and rough surfaces. Methods of calculating ship wetted surfaces are shown, and the effects of hull curvature and fouling on viscous drag are covered. Criteria for separation, eddying, and vortex motion are given demonstrating how these phenomena can be predicted, and their effects estimated. The rules which govern the inception of cavitation on hulls, appendages, and propellers are described, and methods for estimating their results on performance shown.

Although waves and wavegoing are to be treated much more comprehensively in Volume III of the book (not yet published), Volume II contains some theoretical and observed data on natural surface waves and on ship waves. This leads to a discussion of mathematical ship's lines and of mathematical methods of calculating wavemaking resistance. The present state of this theoretical treatment of hull design is summarized and the applicability of the results of mathematical analysis to practical design of ships is discussed.

With this background of mathematical lines development, the author turns to the historical aspect by discussing the hull forms of several ships which have been built in the past including both conventional and unconventional types. Tables of dimensions and coefficients are given together with typical body plans and longitudinal curves. Extensive references to additional data of this type are listed. Supplementing this information are a series of diagrams of flow patterns around different ship forms; methods of predicting flow patterns on new designs are illustrated. This type of information is of great value to the designer in locating bilge keels, control surfaces, and propulsive devices.

Next, the author returns to a discussion of the dynamic lift of planing surfaces. This section discusses in detail the forces involved in planing craft and gives quantitative data which can be used in design and in the prediction of performance.

Methods of estimating the resistance of ships are divided into air and wind resistance, appendage resistance, and residual resistance. These estimating methods summarize the data from various sources, and illustrate those which are the most applicable to any given design problem. Except for numerous examples, the actual data or sets of contours are not given, but the reader is referred to other specific sources for this information. Together with the frictional resistance information given earlier, methods by which the total resistance of the ship can be estimated, are described. This is supplemented by information on the effect of the running attitude of the ship on the total resistance.

The prediction of propulsion device performance is handled in much the same way. A general description is given of the performance which can be expected from screw propellers, paddle wheels, rotating-blade propellers, hydraulic and gas jet propulsion devices, and controllable pitch propellers. Rules-of-thumb are given for estimating perform-

ance when insufficient data are available.

The resistance and the propulsion device performance information are then combined to calculate the horsepower-RPM-speed relationships of a completed ship. Methods are given for determining the effect of altered draft and trim, the hull-propeller interactions of wake fraction, thrust deduction, and relative rotative efficiency, and the effect of additional roughness and fouling. Merit factors are discussed as are variations in operating conditions, backing, and maneuvering. The predicted behavior of the ship in confined waters is discussed and methods of estimating added mass in unsteady motion of the ship are given.

This concludes Part 3 of the book. Up to this point the reader has been provided a basic understanding of hydrodynamic flow phenomena, the relationship of these phenomena to actual ships, and methods of predicting the effect of these phenomena in ship design. He thus has all of the tools and materials necessary to put together a ship designed on the basis of fundamental hydrodynamics. It remains for the author to tie all of these factors into a single presentation in the actual hydrodynamic design of a ship. This he does in Part 4.

Design, for the naval architect and marine engineer, is defined as, "the art of fashioning a ship by an intelligent and logical selection of those features of form, size, proportions, and arrangement which are open to his choice, in combination with those features which are imposed upon him by circumstances beyond his control." The circumstances beyond the designer's control are set forth in the form of specifications insofar as they affect the hydrodynamic design of the ship. In order to illustrate as wide a range of design parameters as possible, the author has purposely chosen a set of conditions which are difficult to meet. The design is to be that of a combination passenger and cargo vessel carrying both high-class package and liquid bulk cargo between the hypothetical ports of Amalo, Bacine, and Correo, hence the project name "ABC Design." Its route requires this ship to operate in both fresh and salt water, in a shallow river, and in areas where its steering and backing characteristics must be excellent. It must maintain a high sustained sea speed even in poor weather conditions, and must be free of undue rolling and pitching. These, and the other hydrodynamic requirements imposed, require ingenuity and a marked degree of hydrodynamic knowledge to evolve a satisfactory design. Like the mystery novel in which a perfect crime is committed in the first chapter, one wonders whether the writer is going to be able to unravel it by the time the book is finished.

Unlike the mystery writer, the author of this book has disclosed all the tools of his trade in advance and his cast of characters has been vividly portrayed. It remains to see the skill with which he puts them together in a detailed and logical form to bring his story to a successful conclusion.

This he does, accompanying his design decisions with a story showing the logic of his choices, and describing what might occur had his choices been otherwise. He moves skillfully through the steps of preliminary design, the design of the underwater body, and the design of the abovewater form. To expand somewhat upon the normal design procedure for the purpose of illustration, two different designs are actually evolved. One of these is a single screw, transom stern design, and the other is a single screw arch-type stern design.

The same logic is used in approaching the propulsion device selection and design. The available propeller design charts of R. E. Froude, D. W. Taylor, K. Schaffran, W. Schmidt, K. E. Schoenherr, L. Troost, J. R. Kane, H. H. W. Keith, J. G. Hill, C. W. Prohaska, F. M. Lewis, and W. E. Ferman are listed, and their use described together with comments on their comparative value. From selected charts, the preliminary design of the propeller for the ABC ship is made, and then the detailed hydrodynamic design of the wheel by means of modern theory is described in complete detail.

It is naturally impossible in the design of a ship for one service to include all of the facets of hydrodynamic flow which may be encountered by the naval architect. Supplementary information is therefore given on the design of alternative types of propulsion devices, on hulls for use in shallow and confined water, and for fixed and movable appendages which were not included in the ABC design. The necessity for hull smoothness is discussed and methods of obtaining a hydrodynamically smooth ship are suggested.

Special purpose craft offer many complex design problems. These could not be completely covered in this book, but they are discussed in a general way and the reader is referred to numerous books and papers from which detailed information may be obtained. Types such as canoes, racing shells, launches, bulk carriers, straight-element designs, fireboats, dredges, box-shaped hulls, floating drydocks, bridge pontoons, yachts, asymmetric hull forms, multiple-hulled craft, ferry boats, icebreakers, amphibians, landing craft, submarines, lightships, and rescue craft fall into this category.

As an example of the specific design procedure required for special purpose craft, however, the preliminary hydrodynamic design of a motor boat is given. In order to establish its characteristics, it has been designed as a motor tender for the ABC ship. The design is carried through for both a round bottom hull and for a planing-type hull in the form of a complete hull design including propeller and appendages.

To acquaint the reader with the methods of predicting ship performance which are available in modern towing tanks, models of the two ABC ship designs were tested in the David Taylor Model Basin. These models were run both towed, and self-propelled with stock propellers. The step-by-step

procedure of model construction and test is described, and the test results are given. The performance of these two designs is adequate evidence of the immense value of the hydrodynamic principles set forth in this book.

The story ends, then, with the ultimate goal of the naval architect—proof of a well-designed ship. From the fundamentals of hydrodynamic flow to an accomplished design, the story is as well-told as the ship is well-designed.

The book, too, is designed with a purpose. It is not designed for the casual reader or handbook engineer who hopes to leaf through a few pages and come up with the solution to his problem. The book is designed to be read from cover to cover. A complete understanding of each part is essential before moving on to the next part. Once the fundamentals in Volume I have been mastered, it can be laid aside, and the design information in Volume II can be applied with intelligence and skill.

To the novice and student naval architect, this book will provide a basic understanding of ship design that will serve him in good stead throughout his career. To the accomplished naval architect it will provide an insight into the fundamentals of his trade which will surprise him. To the architect of large ships, it will provide much needed tools for the evolution of a successful design. For the designers of special craft and small boats, which have been so long neglected in literature, it summarizes the best design information available. To the ship operator, it will give an understanding of the behavior of his vessel and help him to utilize the forces of hydrodynamic flow to the best advantage. And, within its pages, the marine historian will find one of the most complete summaries of hull and propulsion device design which has ever been written.

A review of this work would not be complete without a brief biography of its author, whose education and experience have given him the broad background without which this book could not have been written. Captain Harold E. Saunders' interest in ships and the sea stemmed naturally from his father, who was a master on both Great Lakes and ocean-going ships. He entered the Naval Academy in 1908, and stood at the top of the class of 1912; in fact, his record at that institution was second only to that of David W. Taylor, who later became his mentor and whose works he has done so much to commemorate.

After receiving his Master of Science degree in Warship Design and Naval Construction in 1917 from the Massachusetts Institute of Technology, Captain Saunders served in the Mare Island Naval Shipyard, the Bureau of Construction and Repair, the Portsmouth Naval Shipyard. In Portsmouth, as Superintendent of New Construction, he served as salvage officer in raising the submarine S-48 in Little Harbor, New Hampshire and the S-4 off Provincetown. For the latter accomplishment, he was awarded the Distinguished Service Medal for "his boundless energy, high technical skill, and excellent judgment." These three qualities have not diminished over the intervening years as those who have been privileged to know him will readily attest.

Following his duty at Portsmouth, Captain Saunders was transferred to the Experimental Model Basin at the Washington Navy Yard, where he quickly mastered the fundamentals of model testing and became an authority in the field. After serving on the staff of Commander Battle Force, United States Fleet and a tour as head of the Final Design Branch of the Bureau of Construction and Repair, he again returned to model towing tank work in connection with the design and construction of the David W. Taylor Model Basin.

From its inception, Captain Saunders was the guiding genius behind the creation of this magnificent laboratory. No detail of its construction was too minute to attract his enthusiastic attention. Through his foresight and insistance upon the highest caliber of materials and workmanship, this establishment has become the finest facility for ship model testing in the world. He served in the capacity of Technical Director, Head of the Technical Division, and finally in 1946 he was made Director of the David Taylor Model Basin.

In 1950 Captain Saunders was awarded the Honorary Degree of Doctor of Science by Stevens Institute of Technology, and in that same year he rereceived the David W. Taylor Gold Medal from the Society of Naval Architects and Marine Engineers, which is the highest honor bestowed by that Society.

For the past eight years Captain Saunders has been assigned as Technical Assistant to the Chief of the Bureau of Ships. Through a special arrangement between the Department of the Navy and the Society of Naval Architects and Marine Engineers he has devoted this period to the writing of *Hydrodynamics in Ship Design*.

Had this book never been written, the author's place in the history of naval architecture would have been guaranteed. Its publication can only add even more glory to an already distinguished career. The profession can be humbly grateful that the insight, knowledge, and experience gained in almost fifty years of service is made available in this monumental work.

ENGINEERING PROPERTIES AND APPLICATIONS OF PLASTICS

By Gilbert Ford Kinney
John Wiley & Sons, Inc.,
Publishers
269 pages
$6.75
Publication date 7 August 1957

The author of this book, which this reviewer considers to be a very valuable addition to the library of the practicing engineer, is Professor of Chemical Engineering at the U.S. Naval Postgraduate School at Monterey, California. He has occupied this position since 1946.

The arrangement of the book is excellent.

Chapter 1, in 6 pages introduces the subject with the chapter title "The General Nature of Plastics." This is followed by 11 chapters, each devoted to one family or group of plastics as follows:

Polyethylene
Polyvynol Chloride
Polystyrone
The Acrylic Plastics
Other Vinyl-type Plastics
The Cellulose Plastics
Phenolic Plastics
The Amino Plastics
Polyesters, Polyamides and Expoxies
Silicones
The Rubbers

Each chapter presents the chemical, physical, optical, thermal and electrical characteristics of the family and the advantages and limitations of application.

Following these are a chapter on Molding Methods and then five chapters which, respectively, cover

Engineering Properties
Thermal Properties
Optical Properties
Electrical Properties
Chemistry of Plastics

Finally are two general tables. The first gives General Characteristics and Typical Applications of 16 plastics. This is a very informative table designed for quick reference. The second table presents Typical Properties for Representative Plastics measured in Molded Specimens. Because of wide variation in properties of any plastic the book carries a caution against use of this table for its exact numerical values.

Although this book will not provide a complete education in plastics engineering it certainly does present the kernel of the subject so that the direction to move in to obtain full knowledge is pretty well indicated.

GLASS REINFORCED PLASTICS

Edited by Philip Morgan
Editor of "British Plastics"
Published by Philosophical Library, Inc.,
15 East 40th Street, New York 16, N.Y.
265 pages
$15.00

This book is a revised and expanded edition of the original work which was published but three years ago in 1954. To meet the demand for the first editions three impressions had to be made. Since this demand seemed to fully justify such effort, a complete revision, which includes several rewritten chapters and three added ones has been made.

Both British and American practices are covered by the book but the several contributors are all British and in spots typical words and phraseology, somewhat strange to the American mind appear.

The book is a compilation of 18 chapters and an appendix each prepared by a separate author working independently. The editor made no effort to correlate test figures which may be included in any chapter so each must be read within the context of its own chapter.

The contents with the authors are:

Chapter I	Glass Fibre Forms and Properties K. J. Brookfield, Fibreglass, Ltd.
Chapter II	The Chemistry of Unsaturated Polyester and Allyl Resons C. P. Vale, B. I. P. Chemicals, Ltd.
Chapter III	Polyester Types and Properties E. M. Evans, British Resin Products, Ltd.
Chapter IV	Ancillaries for Polyesters Brian Parkyn, Scott Bader & Co., Ltd.
Chapter V	Glass Fibres with Phenolic Resins N. W. Newstubb, Bakelite, Ltd.

Chapter VI	Silicone, Melamine, and Furane Resins H. A. Collinson, Leicester, Lovell & Co., Ltd. and R. McDowall, Leicester, Lovell & Co., Ltd.
Chapter VII	Epoxide Resins W. J. Marmion, Shell Chemical Company, Ltd.
Chapter VIII	Commercial Moulding Processes G. C. Hulbert, Scott Bader & Co., Ltd.
Chapter IX	Methods of Mass Production A. E. Dean, The Micanite and Insulators Co., Ltd.
Chapter X	Continuous Resin Injection for Glass Fibre Moulding J. Rees, Bristol Aircraft, Ltd.
Chapter XI	Tube and Rod Production A. R. Henning, Fibreglass, Ltd., and C. B. Cuming, Thermotank Plastic Engineering, Ltd.
Chapter XII	Design and Properties of Structures Lorne Welch, Microcell, Ltd.
Chapter XIII	Glass Reinforced Plastics in the Aircraft Industry Richard Wood, *British Plastics*
Chapter XIV	Glass Fibre Laminates in the Electrical Field J. K. Hyde, Mica and Micanite Supplies, Ltd.
Chapter XV	Automobile Bodywork and other Transport Applications Richard Wood, *British Plastics*
Chapter XVI	Polyester/Glass Boat Hulls P. D. deLaszlo, Halmetic, Ltd.
Chapter XVII	Chemical Engineering Applications V. Evans, Prodorite, Ltd.
Chapter XVIII	Miscellaneous Applications Patrick Moxey, Bakelite, Ltd..
Appendix	Structural Models Peter H. H. Bishop, Royal Aircraft Establishment Farnsborough, Hants

BASIC RESEARCH—A NATIONAL RESOURCE,

Issued by the National Science Foundation
64 pp. Procurable from the Superintendent of
Documents, U. S. Government Printing Office
Washington 25, D.C.

Presenting a strong case for increased support for basic research in the sciences from private as well as public sources, *Basic Research—A National Resource,* commends for public consideration several far-reaching measures affecting the future of science in the United States.

In addition to a statistical and descriptive analysis of the basic research effort of the United States, the report suggests consideration of a number of possible ways to encourage research in science. These include increased support for research at universities which conforms to their educational and scholarly programs with reduction of support for enterprises for which the university is not uniquely fitted; a redefinition of the rules under which tax exemption privileges are now accorded to nonprofit research institutes; changes in Federal income tax laws to stimulate private philanthropic giving for basic research; and a program of Federal grants in aid to States designed to increase State financial participation in the support of basic research.

"The Foundation recognizes that some of the issues raised by this study may bring out differences of opinion," said Alan T. Waterman, Director, in releasing the report. "Many affect public policy, however, and should therefore be discussed in public forums. Differences can be resolved when the issues involved are clearly understood.

"The report helps to establish the meaning and concept of basic research—obscured in a fog created by the indiscriminate use of the word 'research' with reference to testing, development, invention. Finally, the report represents a further step to carry out the mandate given the Foundation by the Congress to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the sciences."

The report is divided into four parts—a brief (7-page) general summary; a section on the rise of basic research with three examples of active and promising research—radio astronomy, virus heredity, and translation by electronics; a section on basic research in the United States which describes the relationship of basic research to interested segments of the economy—educational institutions, industry, and government; and a final section on strengthening basic research which itemizes positive steps that can be taken to stimulate the progress of basic research.

VICE ADMIRAL BERNARD EDWARD MANSEAU U. S. Navy, (Retired)

On Tuesday, 5 November 1957, Vice Admiral Bernard E. Manseau, U.S. Navy, Retired, died at the Bethesda Naval Hospital.

At the time of his death Admiral Manseau was serving on the Council of the Society, having been elected in December 1956 to serve two years. He joined the Society in October 1949.

Bernard Edward Manseau was born in Jefferson, S.D., on October 21, 1899. He attended Lead (South Dakota) High School, before his appointment to the U.S. Naval Academy in 1918.

Graduated and commissioned Ensign on June 2, 1922, he transferred on June 3, 1925 to the Construction Corps in the rank of Lieutenant(jg). When the Construction Corps was abolished in June 1940, he returned to the Line of the Navy and was designated for engineering duty only. He subsequently attained the rank of Captain to date from June 21, 1944, and on August 10, 1951, his nomination to the rank of Rear Admiral was confirmed by the U.S. Senate.

Following graduation in 1922, he joined the USS "Idaho" and served aboard until September 1924. He reported for instruction in Naval architecture at the Postgraduate School, Annapolis, Md. He continued the course from June 1925, at the Massachusetts Institute of Technology at Cambridge, where he received the degree of Master of Science in June 1927. He completed a course in chemical warfare at the Edgewood (Maryland) Arsenal in July 1927.

From 1930 to 1932 he was an instructor at the Naval Academy, after which he joined the USS "Dobbin" as Assistant to the Repair Officer. Detached from that ship in July 1934, he reported for duty at the Puget Sound Navy Yard, Bremerton, Wash. He remained there until November 1937, when he transferred to the Navy Yard, Pearl Harbor, Territory of Hawaii, to serve for the first six months as Shop Superintendent and later as Hull Superintendent. "For distinguished devotion to duty . . . during the attack on the Fleet in Pearl Harbor, Territory of Hawaii, by Japanese forces on December 7, 1941 . . ." he received a Letter of Commendation with authorization to wear the Commendation Ribbon from the Secretary of the Navy.

In May 1942 he was assigned to the Bureau of Ships, Navy department, Washington, D.C., and for "exceptionally meritorious conduct . . . in the administration and development of the ship salvage organization of the United States Navy during World War II . . ." was awarded the Legion of Merit.

He had detached duty between March and September 1946 as Commander of the Salvage Unit of Joint Task Force ONE during "Operation CROSSROADS" (the atomic bomb tests of Bikini Atoll in July 1946). For his service he was awarded a Gold Star in lieu of a second Legion of Merit.

In January 1947, he reported as Production Officer of the Mare Island (California) Naval Shipyard. In March 1949 he became Commander of the Naval Shipyard, San Francisco, California. In June 1950 he returned to the Mare Island Shipyard to serve as Commander of that activity until July 1952, when he reported as Director of Industrial Surveys, in the Office of the Chief of Naval Operations, Navy Department. In November 1952, he was assigned to the Bureau of Ships, as Assistant Chief of the Bureau for Field Activities. In August 1953, he was designated Deputy and Assistant Chief of the Bureau of Ships. While serving in this position he suffered a heart attack on 3 April 1957 from which he never fully recovered. He was transferred to the retired list on 1 August 1957.

Rear Admiral Manseau and his wife, the former Dorothy M. Hess of Jersey City, New Jersey, have three daughters: Louise M. Packer, Dorothy L. Huffer; and Lani Marie Manseau. Their official address is 610 Sawyer Street, Lead, South Dakota.

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

The Society is happy to announce that the following have become members since the publication of the August, 1957, JOURNAL.

NAVAL

Borkowski, John Vincent, Lieut. Commander, USNR
Foster Wheeler Corporation
165 Broadway, New York 6, N.Y.

Bramkamp, John Lewis, Lieut., USNR
Atomic Energy Commission
Mail: 512 Calvin Lane, Rockville, Md.

Brown, Lawrence Wilbert, Commander, USNR
Stromberg-Carlson Company
Mail: 11 Burrows Drive, Rochester, N.Y.

Carson, A. C., Lieut. Commander, USN
5131 September St., San Diego, Calif.

Crocco, Francis B., Captain, USNR
Rep. Survey for American Bureau of Shipping
Mail: P.O. Box 1411, San Juan, P.R.

Farber, Karl Heinz, Lieutenant, USN
USS *Wisconsin* (BB 64)
c/o Fleet P.O., New York, N.Y.

Krug, Harry E. P., Lieutenant, USNR
USS *Wantuck* (APO 125)
c/o Fleet P.O., San Francisco, Calif.

Maclean, Walter Marcus, Lieutenant, USNR
Design Engineer for Morris Guralnick
Mail: 625 Lexington, El Corrito, Calif.

Maier, Ernest August, Lieutenant, USNR-R
Marine Designer, Esso Shipping Co.
60 W. 49th St., New York, N.Y.
Mail: 54 Annuskemunnca Road, Babylon, N.Y.

Peterson, Quentin Kivley, Lieutenant, USNR
Research Engineer, North American Aviation
Mail: 1127 10th St., Manhattan Beach, Calif.

Smith, Chester C., Rear Admiral, USN
NATO Standing Group, Room L-960
Pentagon, Washington 25, D.C.

Turner, Charles Wesley III, Commander, USN
Chief Staff Officer, Navy Section, MAAG, Navy
No. 3840, c/o Fleet P.O., San Francisco, Calif.

VanDenburgh, William Nelson, Captain, USN
Inspector of Naval Material Industrial Reserve
Shipyard, Building 13, Port Newark, Newark 5, N.J.

CIVIL

Babcock, Hugh H., Asst. Secretary, Asst. Treasurer
Union Carbide Corp., 30 E. 42d St., New York 17, N.Y.

Hauck, Adam Edward, Asst. Sales Manager
Buffalo Pump Div., Buffalo Forge Co., Buffalo, N.Y.

Kobler, Julian S., Supervising Welding Engineer
Washington Naval Gun Factory
Mail: The Woodner, 3636 16th St., NW.,
Washington 10, D.C.

Moise, James DeLeon
Westinghouse Electric Corp.
Lester P.O., Philadelphia, Pa.

Robinson, Harold F., Design Manager
Bethlehem Steel Co., Shipbuilding Division
Quincy 69, Mass.

Rodgers, Joseph L.
Bakelite Co., 30 E. 42d St., New York 17, N.Y.

ASSOCIATE

Baer, Walter O., Division Manager
Cutler-Hammer, Inc., 315 N. 12th St., Milwaukee, Wis.

Balcken, Walter Harold, Navy and Marine Sales
Cutler-Hammer, Inc., 315 N. 12th St., Milwaukee, Wis.

Hauver, Gordon Nelson, Asst. Engineer and Supervisor
Cutler-Hammer, Inc., 315 N. 12th St., Milwaukee, Wis.

Inglis, James Allen, Lieut. (E) Royal Canadian Navy
c/o HMS *Ontario*, Victoria, B.C., Canada

Nelson, Kenneth M., Division Manager
Cutler-Hammer, Inc., 315 N. 12th St., Milwaukee, Wis.

Towey, Francis Xavier, 2d Lieutenant, USA
Box 9360, Building No. 2, Fort Bliss, Texas

The Society is grieved to report receipt of the death of the following:

COOKSON, LEIGHTON F., Naval Member
HOFFMAN, WARREN E., Civil Member
WARTMAN, S. L., Naval Member
MANSEAU, BERNARD E., Naval Member
WENZ, PHILIP J., Civil Member
CURTIS, RICHARD COOPER, Civil Member

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

ASSOCIATION NOTES

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

We have a new supply of lapel buttons, in the form of the Society's official seal. These may be purchased by any member for fifty cents ($0.50) each.

By decision of the Council the official coloring of the Society seal is as it appears on the cover of this Journal. This is a reversal of the colors on the old lapel buttons. The size, one-half inch in diameter, remains the same.

Any member who wishes to exchange an old button for a new one may do so *free of charge*. Just send in the old button with your name and address.

PERMISSION TO REPRINT

All material published in the JOURNAL, except the articles which are prefaced with an "Acknowledgement," are copyrighted by the American Society of Naval Engineers.

Permission is granted to reprint any copyrighted material contained herein if the following conditions are met:

a) The article is reprinted in full. Extracts or summaries or condensations may be printed with the consent of the author.

b) Credit is given to the JOURNAL with reference to the issue.

c) Credit is given to the author.

d) If the author is a military officer or a civilian employe of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 20 reprint copies of his article free of charge. Additional copies may be purchased from the Society *if the request is received 30 days prior to the publication date which is the 25th of the issue month.* Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

APPLICATION FOR MEMBERSHIP

IN THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

(See reverse side for required qualifications for various classes of membership)

Date _____

I, _____ hereby apply for membership in the American Society of Naval Engineers, Inc., and enclose $10.00 as my annual membership dues for the year _____ $8.00 of which is for a subscription to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., for one year. I submit the following information:

For Naval Membership

Name _____
(First) (Middle) (Last)

Rank _____ File No. _____

Business connection and position, if any _____

For Civil Membership

Name _____
(First) (Middle) (Last)

Years in engineering work _____

Years in responsible charge of important work _____

Present business connection and position _____

Recommended by (two members) _____

_____

For Associate Membership

Name _____
(First) (Middle) (Last)

Rank, if Commissioned Officer of U.S. Army or of foreign military or Naval service _____

Business connection and position _____

Recommended by (one member) _____

_____
Signature of Applicant

Address for JOURNAL and Mail

_____

_____

MAIL TO SECRETARY-TREASURER

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Suite 1004, Continental Building

1012 14th St., N.W. Washington 5, D.C.

Company Memberships Not Available

QUALIFICATION FOR MEMBERSHIP

Commissioned and ex-commissioned officers, warrant and ex-warrant officers, and reserve (commissioned and warrant) officers of the Navy, Coast Guard and Marine Corps, of the United States, active or retired, shall be eligible as Naval Members. Persons eligible as Naval Members shall be admitted upon application and payment of annual dues.

Persons in civil life whose knowledge of engineering is such that they can cooperate with Naval engineers in the promotion of professional knowledge may be eligible as Civil Members. They shall have been in the active practice of an engineering profession for at least eight years and in responsible charge of important work for five years, and shall be qualified to design as well as to direct engineering work. Fulfilling the duties of a professor of engineering who is in charge of a department in a college or school of accepted standing shall be taken as an equivalent to an equal number of years of active practice. Graduation from a school of engineering of recognized standing shall be considered as equivalent to two years of active practice. Persons eligible as Civil Members may be admitted upon application and payment of annual dues, provided that the application is accompanied by the recommendation of two members and provided that the application shall receive the approval of a majority of the Council.

Persons in civil life who are not eligible for civil membership, but who are especially interested in naval matters or the merchant marine may be eligible as Associate Members. Commissioned officers of the United States Army, United States Air Force and of foreign military and naval services may be eligible as associate members. Persons eligible to associate membership may be admitted upon application and payment of annual dues, provided the application has the recommendation of a member and provided the application shall receive the approval of a majority of the Council, except that in the case of commissioned officers of the United States Army, of the United States Air Force, and of foreign naval and military services, the recommendation of a member will not be required.

Undergraduates at schools to be named by and under regulations to be issued by the Council shall be admitted as Junior Members at one-half the dues of regular members during their course and for one year following graduation, after which time junior membership will be terminated, the member to have the privilege of transferring to regular membership in the appropriate category.

Associate and Junior Members shall be entitled to all the privileges of other members except voting and holding office.

The annual dues shall be $10.00, payable on 1 January in advance, of which $8.00 shall be for subscription to the JOURNAL of the American Society of Naval Engineers, Inc., for one year.

JOURNAL OF THE
AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

NOVEMBER, 1957

PART II

BY-LAWS OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Effective 1 January 1958

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1. The Association shall be known as the AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

2. The object of the Society shall be to promote a knowledge of marine engineering and naval architecture by reading, discussing and publishing papers on professional subjects; by bringing together the results of experience acquired by engineers in all parts of the world and publishing them in the JOURNAL of the Society; by publishing the results of such experimental and other inquiries as may be deemed of value to the advancement of the science; and by recording historical events in the

lives of engineers. The Society shall not be conducted for profit. Should any profit accrue as a result of its operations, such profit shall not be distributed but shall be held for the objects of the Society as set forth herein.

3. The officers of the Society shall be a President, a Secretary-Treasurer, and other members of a Council.

4. The President and the Secretary-Treasurer shall be Commissioned Officers, active or retired, of the regular Navy, Marine Corps, or the Coast Guard of the United States.

5. The Council shall be composed of eleven members, two of whom shall be the President and the Secretary-Treasurer of the Society. Of the remaining members, four shall be officers of the regular United States Navy; one shall be an officer of the United States Coast Guard; two shall be officers of the United States Naval Reserve or United States Coast Guard Reserve, and two shall be civilians. The President and Secretary-Treasurer shall act as President and Secretary-Treasurer of the Council. In the absence of the President, the senior Naval Member of the Council in his second year shall preside.

6. Residence in the City of Washington, D. C., or in the vicinity thereof, shall be a necessary qualification for any Council Member and for the Assistant Secretary-Treasurer.

7. Removal from the city or its vicinity shall constitute a disability on account of which the Council shall declare any office vacant.

8. The President and Secretary-Treasurer shall be elected annually. Other members of the Council shall be elected for a term of two years, about one-half being elected each year. All officers shall assume office on 1 January.

9. The President shall exercise the usual duties of that office.

10. The Secretary-Treasurer shall conduct the correspondence of the Society and its financial transactions. Under the

supervision of the Council, he shall edit and publish the JOURNAL of the Society. He shall deposit the funds of the Society in its name in a bank approved by the Council and shall withdraw same by check. He shall keep the securities of the Society in a safe deposit box held in its name. He shall submit an annual financial statement which shall be audited by three members of the Society. In addition, he shall submit an annual budget for approval by the Council. He shall receive such salary as the Council may provide.

11. The Council may appoint a Naval Member as Assistant Secretary-Treasurer, who, in addition to other duties, shall perform the duties of the Secretary-Treasurer during the absence of the latter. He shall receive such salary as the Council may provide. This appointment shall be for a stated term which shall not extend beyond the term of office of the incumbent Secretary-Treasurer.

12. The Council shall direct and manage the affairs of the Society and shall supervise the editing and publishing of the JOURNAL. It shall require that all personnel of the Society handling its funds or securities shall be bonded. It shall fill all vacancies which may occur during a year. In case of death or disability of a member of the Council, the Council shall declare the office vacant. The Council shall have authority to decide upon questions of disability. The Council shall have authority to employ such clerical assistance as may be required at such rate of compensation as it may deem proper. The Council may authorize the acceptance of subscriptions for the JOURNAL of the Society from those who are not members as hereinafter provided, and also the sale of single copies of the JOURNAL, and of reprints of separate articles, and may fix the prices thereof; it may also authorize the use of certain portions of the JOURNAL for appropriate advertisements, and fix the rate of payment therefor. The Council may authorize the formation of local chapters of the Society under such rules and regulations as it

shall adopt. The Society may incur financial obligations only by action of the Council.

13. The Council shall meet at the call of the President, or of any two members. One such meeting shall be the nucleus of the annual meeting. Six shall constitute a quorum for business.

14. The Society shall be composed of Honorary Members, Naval Members, Civil Members, Associate Members and Junior Members.

15. Commissioned and ex-commissioned officers, warrant and ex-warrant officers, and reserve (commissioned and warrant) officers of the Navy, Coast Guard and Marine Corps, of the United States, active or retired, shall be eligible as Naval Members. Persons eligible as Naval Members shall be admitted upon application and payment of annual dues.

16. Persons in civil life whose knowledge of engineering is such that they can cooperate with Naval engineers in the promotion of professional knowledge may be eligible as Civil Members. They shall have been in the active practice of an engineering profession for at least eight years and in responsible charge of important work for five years, and shall be qualified to design as well as to direct engineering work. Fulfilling the duties of a professor of engineering who is in charge of a department in a college or school of accepted standing shall be taken as an equivalent to an equal number of years of active practice. Graduation from a school of engineering of recognized standing shall be considered as equivalent to two years of active practice. Persons eligible as Civil Members may be admitted upon application and payment of annual dues, provided that the application is accompanied by the recommendation of two members and provided that the application shall receive the approval of a majority of the Council.

17. Persons in civil life who are not eligible for civil membership, but who are especially interested in naval matters or the merchant marine may be eligible as Associate Members. Com-

missioned officers of the United States Army, United States Air Force and of foreign military and naval services may be eligible as associate members. Persons eligible to associate membership may be admitted upon application and payment of annual dues, provided the application has the recomendation of a member and provided the application shall receive the approval of a majority of the Council, except that in the case of commissioned officers of the United States Army, of the United States Air Force, and of foreign naval and military services, the recommendation of a member will not be required.

18. Undergraduates at schools to be named by and under regulations to be issued by the Council shall be admitted as Junior Members at one-half the dues of regular members during their course and for one year following graduation, after which time junior membership will be terminated, the member to have the privilege of transfering to regular membership in the appropriate category.

19. Associate and Junior Members shall be entitled to all the privileges of other members except voting and holding office.

20. Naval, Civil and Associate Members may be constituted Life Members under such rules and regulations and at such cost as the Council may establish.

21. The Secretary of Defense, the Deputy Secretary of Defense, the Secretary of the Navy, the Under Secretary of the Navy, and all Assistant Secretaries of Defense and of the Navy, who are appointed by the President and with the consent of the Senate, the Chiefs of all material bureaus of the Navy Department—that is the Chief of the Bureau of Ships, the Chief of the Bureau of Ordnance, the Chief of the Bureau of Yards and Docks, the Chief of the Bureau of Aeronautics,—and the Engineer-in-Chief of the United States Coast Guard, all ex-Presidents of the Society, all prize essayists, the Deputy Chief of the Bureau of Ships, the Chief of Naval Material, the Chief of Naval Research, and such other persons as the Society may

elect, shall be Honorary Members. To be elegible for Honorary Membership, such other person must receive the unanimous vote of the Council before his name may be presented to the society; and the favorable vote of two-thirds of the members voting shall be necessary for election. The procedure in voting for persons whose names have been presented by the Council as candidates for Honorary Membership shall be similar to that followed for the election of officers. Honorary Members shall be exempt from payment of dues.

22. The annual dues shall be $10.00 payable on 1 January, in advance. If a member shall be in arrears for a period of nine months, the Secretary shall send notice to that effect under date of 1 October, by registered mail, to such member's last known address. If such member's dues shall remain unpaid on the 31st day of December following this notice, his name shall be dropped from the rolls of the Society. He may be reinstated by the Council only on written application and payment of all arrears at time of separation.

23. All moneys, all correspondence and all matter intended for publication shall be sent to the Secretary-Treasurer.

24. The Society shall meet annually in the City of Washington, D. C., in the first half of October, for the purpose of making and receiving nominations to offices for the following years, and for the transaction of such other business as may be presented. At least one month prior to the annual meeting, the President shall appoint a Nominating Committee, the duty of which shall be to present to the annual meeting at least two nominations for each office to be filled, except as noted below, having due regard to the requirements of Articles 4 and 5 of the By-Laws. In the case of nominations for President of the Society, only one nomination need be presented. Additional nominations, either oral or in writing, may be made at the annual meeting by any Naval, Civil or Honorary Member. At the annual meeting, nominations for each office shall be closed upon a majority vote of the

members present. The consent of a nominee to accept office if elected must be assured. Any member may be placed in nomination for any number of offices for which he is eligible.

25. Immediately following the annual meeting, the Secretary-Treasurer shall prepare and mail to each Naval, Honorary and Civil Member, a ballot showing the name of each candidate and the office to which he is nominated. Each ballot shall be marked and mailed in a special ballot envelope provided each member. The envelope need not be signed; the ballot shall not be signed. To be counted a ballot must be received at the office of the Society prior to December 26th. Voting by proxy is prohibited.

26. Some time between December 26th and December 30th, a committee of three Members appointed by the President shall open and count the ballots. After completion of this count, a meeting of the Council shall be called to examine the report of this committee. The Council shall then announce the names of the officers elected for the following years. In case of a tie, the presiding officer shall cast the deciding vote. In the event of a candidate receiving the greatest number of votes for more than one office, he shall decide which he will accept.

27. The Council may call a meeting of the Society whenever it deems it necessary or advisable.

28. The Council shall have authority to establish such other rules and regulations as may be necessary for the government of the Society and for the conduct of its affairs, provided that such rules and regulations do not conflict with the provision of these By-Laws.

29. Motions to amend these By-Laws, or to make new By-Laws, must be in writing, and must lie over at least three months, during which time notice thereof shall be sent to all Naval, Honorary and Civil Members. The assent of two-thirds of the members voting shall be necessary to amend or adopt. The procedure in voting on changes in the By-Laws shall be similar to that followed in the election of officers.

Secretaries of the

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Captain J. E. Hamilton, U. S. Navy Retired, Secretary-Treasurer
Captain Robert B. Madden, U. S. N. Assistant Secretary-Treasurer

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Past Secretaries

1889	*P. A. Engineer R. S. Griffin, U. S. Navy*
1890	*Assistant Engineer W. M. McFarland, U. S. Navy*
1891	*Assistant Engineer Emil Theiss, U. S. Navy*
1892-93	*P. A. Engineer W. M. McFarland, U. S. Navy*
1894-95	*P. A. Engineer R. S. Griffin, U. S. Navy*
1896-97	*P. A. Engineer F. C. Bieg, U. S. Navy*
1898	*P. A. Engineer W. M. McFarland, U. S. Navy*
1899	*Chief Engineer A. B. Willits, U. S. Navy*
1900	*Lt. Cmdr. A. B. Willits, U. S. Navy*
1901	*Lieutenant B. C. Bryan, U. S. Navy*
1902	*Lieutenant C. W. Dyson, U. S. Navy*
1903	*Lt. Cmdr. John R. Edwards, U. S. Navy*
1904	*Lieutenant M. E. Reed, U. S. Navy*
1905	*Lieutenant W. W. White, U. S. Navy*
1906	*Lieutenant C. K. Mallory, U. S. Navy*
1907-08	*Lt. Comdr. T. C. Fenton, U. S. Navy*
1908-10	**Lieutenant H. C. Dinger, U. S. Navy**
1911	*Commander U. T. Holmes, U. S. Navy*
1912	*Lieutenant John Halligan, U. S. Navy* *Lt. Comdr. E. L. Bennett, U. S. Navy*
1913	**Lieutenant O. L. Cox, U. S. Navy**
1914	**Lt. Comdr. H. C. Dinger, U. S. Navy**
1915-16	*Lieutenant A. T. Church, U. S. Navy*
1917	**Lt. Comdr. J. O. Richardson, U. S. Navy**
1917-19	*Lt. Comdr. F. W. Sterling, U. S. Navy*
1919-21	**Commander J. S. Evans, U. S. Navy**
1921-23	**Commander S. M. Robinson, U. S. Navy**
1924-25	**Commander Bryson Bruce, U. S. Navy**
1926	**Commander A. M. Charlton, U. S. Navy**
1927-28	**Commander H. B. Hird, U. S. Navy**
1928	**Captain O. L. Cox, U. S. Navy**
1929-30	*Commander H. T. Smith, U. S. Navy*
1931	**Captain O. L. Cox, U. S. Navy**
1932	**Commander H. F. D. Davis, U. S. Navy**
1933-34	**Commander H. B. Hird, U. S. Navy**
1935-36	**Commander C. S. Gillette, U. S. Navy**
1936-38	**Commander Roger W. Paine, U. S. Navy**
1938-40	**Lt. Comdr. Guy Chadwick, U. S. Navy**
1940-44	**Captain J. E. Hamilton, U. S. Navy**
1945	**Commander R. T. Sutherland, Jr., U. S. Navy**
1945-48	**Captain F. W. Walton, U. S. Navy**
1948-51	**Captain J. E. Hamilton, U. S. Navy**

Past Assistant Secretaries

1939-40	**Lieutenant Milo B. Williams (C.C.) U. S. Navy**
1941-44	**Lieutenant Robert T. Sutherland, Jr., U.S. Navy**
1945	**Captain F. W. Walton, U.S. Navy**
1945-47	**Commander Floyd B. Schultz, U.S. Navy**
1947-49	**Commander C. H. Meigs, U. S. Navy**
1949-50	**Commander Frank C. Jones, U. S. Navy**

Clerk and Administrative Assistant

1908- Mr. Arthur G. Fessenden

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*Names in italics deceased